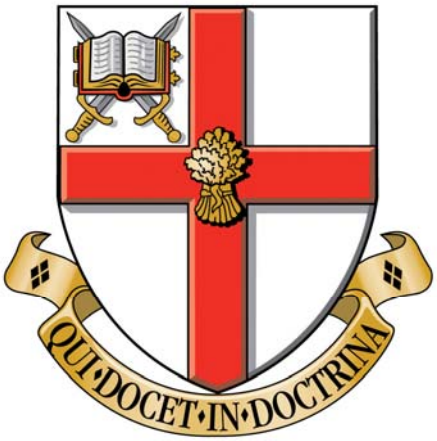


University of Chester

# The prediction of maximal oxygen uptake from a perceptually-regulated exercise test (PRET)

**Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of**

**Doctor of Philosophy**

**Michael M. Morris**

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## Author's Declaration

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## Abstract

The Borg 6–20 rating of perceived exertion (RPE) scale is a common measure reported during exercise testing and training, and is usually taken as a response measurement to provide a subjective assessment of exercise intensity. A lesser used application of the scale is for regulating exercise intensity, referred to as its 'production mode'. Recent research on this topic initiated by Eston *et al*. (2005) has led to a novel application of this procedure as a means of predicting an individual's maximal oxygen uptake ($\dot{V}O_2max$) via a perceptually-regulated exercise test (PRET). The PRET could play a significant role in guiding exercise prescription and monitoring cardiorespiratory fitness levels in situations where the normal heart rate response is affected. The aim of this thesis is to develop further and test the integrity of the PRET technique. Firstly, a review of the evidence on the validity and reliability of the Borg RPE scale when used to regulate exercise intensity in healthy and unhealthy adults is presented, as to-date, no scholarly publication has synthesised the body of knowledge on this specific application of the scale. Subsequently, four studies were completed to investigate the effects of different methodological variations on the predictive capabilities of the PRET, including an examination (for the first time) of its utility among heart failure patients (Study 4). Study 1 re-visited the validity and reliability of the PRET technique utilising a modified protocol of differing durations (2 and 4 min bouts), with revised instructions and placing the graded exercise test (GXT) as the final trial during cycle ergometry. Superior results were observed to those reported in previous investigations (Eston *et al*., 2008; Faulkner *et al*. 2007; Eston *et al*., 2006) during

the 3 min trial, further reinforcing the validity and reliability of this technique. Accordingly, Study 2 was the first to investigate the reliability and validity of a treadmill PRET protocol with a ceiling intensity of RPE 15, rather than RPE 17, and observed that a safer modified PRET (with practice) provides acceptably valid and reliable predictions of $\dot{V}O_2$max in healthy adults. In addition, Study 3 extended the research thus far by investigating the PRET protocol during cycle exercise, once again with a ceiling intensity of RPE 15, and demonstrated that (with practice) a cycle-based PRET can yield reliable and valid predictions of $\dot{V}O_2$max that compare favourably to previous investigations. Finally, given that the research employing a PRET has unanimously alluded to its likely value in clinical populations among whom heart rate as a physiological response to exercise is affected (e.g. via medication) and precluded as a means predicting $\dot{V}O_2$max, Study 4 investigated the utility of a PRET in a beta-blocked population of heart failure patients. In the event, it was observed that a PRET (up to RPE 15) was too strenuous and needs to be capped at an intensity of RPE 13 in this population. In addition a continuous protocol seemed unsuitable due to its length and it was recommended that a discontinuous PRET protocol be investigated. Future research needs to investigate the utilisation of the PRET (i) in different exercise modes; (ii) determine the optimum number of practice trials required; (iii) whether a discontinuous or continuous protocol is more appropariate; (iv) whether the extrapolation should be made to RPE 19 or 20 and; (v) whether the PRET can be employed succesfully in other clinical populations.

# List of Contents

**Chapter 4: Study 2**

*The validity and reliability of predicting maximal oxygen uptake from a treadmill-based sub-maximal perceptually-regulated exercise test.*



**Chapter 5: Study 3**

*The efficacy of predicting maximal oxygen uptake from a shortened perceptually-regulated exercise test (PRET).*

## List of Tables

## List of Figures

## Abbreviations

**ACSM** American College of Sports Medicine

**ANOVA** Analysis of Variance

**b·min$^{-1}$** Beats per minute

**DBP** Diastolic Blood Pressure

**GXT** Graded-exercise Test

**HR** Heart Rate

**% HRmax** Heart rate expressed as a percentage of maximal heart rate

**ICC** Intraclass Correlation Coefficient

**L·min$^{-1}$** Litres per minute

**LoA** Limits of Agreement

**m** Meters

**min** Minutes

**ml·kg$^{-1}$·min$^{-1}$** Millilitres per kilogram per minute

**mM** Millimoles

**mmHg** Millimeters of mercury

***n*** Sample size

***r*** Pearson's correlation coefficient

***R*** *regression analysis*

**rev·min$^{-1}$** Revolutions per minute

**RPE** Ratings of Perceived Exertion

**RR** Respiratory Rate

**s** Seconds

**SBP** Systolic Blood Pressure

**SD** Standard Deviation

**T** Trial

V**$CO_2$** Volume of Carbon Dioxide

**VE** Ventilation

$\dot{V}$**$O_2$** Volume of Oxygen Uptake

$\dot{V}$**$O_2$max** Maximal Oxygen Uptake

$\dot{V}$**$O_2$peak** Peak Oxygen Uptake

**%** $\dot{V}$**$O_2$max** Oxygen uptake expressed as a percentage of maximal oxygen uptake

**VT** Ventilatory Threshold

**W** Watts

**WR** Work Rate

**Operational Definitions**

**Reliability** – This refers to the agreement of the predicted maximal oxygen uptake from the PRET over repeated trials.

**Validity** – This refers to the agreement of the predicted maximal oxygen uptake from the PRET and the measured maximal oxygen uptake from a maximal graded exercise test.

# Chapter 1

# Introduction

## 1.1 Rationale and overview of thesis

Maximal oxygen uptake ($\dot{V}O_2max$) represents the integrated capacity of the cardiovascular, pulmonary and muscle systems to transport, uptake and utilise oxygen (Poole, Wilkerson & Jones, 2008). When expressed in metabolic equivalents (METS) it has been shown to be the single best predictor of all-cause mortality among men with or without cardiovascular disease (Myers, Prakash, Froelicher, Partington & Atwood, 2002), and when expressed as peak or maximal oxygen uptake ($\dot{V}O_2max$) a strong and independent predictor of mortality in patients with known cardiovascular disease (Aijaz, Squires, Thomas, Johnson & Allison, 2009; Kavanagh *et al.,* 2002; Laukkanen, Kurl, Salonen, Rauramaa & Salonen, 2004). It is generally regarded as the criterion measure of cardiorespiratory fitness and is commonly used to assess the effectiveness of exercise training, prescribe exercise training accurately (ACSM, 2010), as well as quantifying the functional predations of chronic diseases such as heart failure, COPD and diabetes (Poole *et al.,* 2008; Howley, Bassett & Welch, 1995; Wasserman, Hansen, Sue, Stringer & Whipp, 2005). However, the direct measurement of $\dot{V}O_2max$ requires expensive equipment, specialist personnel and a maximal effort on the behalf of the participant which raises issues of safety in untrained, elderly and clinical populations.

As a consequence, a number of sub-maximal predictive tests have been developed that can be conducted in non-laboratory environments via cycling (Siconolfi, Cullinane, Carleton & Thompson, 1982; Åstrand & Ryhming, 1954),

walking (Ebbeling, Ward, Puleo, Widrick & Rippe, 1991; Kline *et al.,* 1987), running (Ramsbottom, Brewer & Williams, 1988; Leger & Lambert, 1982) and stepping (Sykes & Roberts, 2004) which all rely on the nearly linear relationship between oxygen consumption and heart rate and an assumed maximal heart rate (i.e., $HR_{max}$ = 220 – age) (Brooks, Fahey, White & Baldwin, 2000). However, there are several limitations to this technique, especially regarding the error associated with the equation used to predict maximum heart rate, which can be as high as 20 beats·min$^{-1}$ (Londeree & Moeschberger, 1984; Buckley, Sim, Eston, Hession & Fox, 2004). Heart rate can also be affected by medications (β-blockers) and environmental conditions (heat), which in turn impacts upon the heart rate - $\dot{V}O_2$ relationship and the subsequent prediction of $\dot{V}O_2$max.

A common measure recorded during exercise testing and training is perceived exertion, which is defined as "the act of detecting and interpreting sensations arising from the body during physical exertion" (Noble & Robertson, 1996, p. 4). The most popular scale for this purpose has been the Borg (1998) 6–20 scale, which is typically applied in its so-called 'estimation mode' whereby exercisers provide a rating of perceived exertion (RPE) at a given point when requested by an investigator. Used in this way the RPE scale has been shown to be a valid and reliable measure of exercise intensity (Carton & Rhodes, 1985; Hampson, Gibson, Lambert & Noakes, 2001; Chen, Fan & Moe, 2002; Groslambert & Mahon, 2006). It is also not affected by medications and environmental conditions (Kang *et al.,* 1998; Eston & Connolly, 1996) and in theory

should not encounter the error associated with heart rate when estimating a person's $\dot{V}O_2$max.

A lesser-used application of RPE has been its regulation of exercise intensity, referred to as its 'production mode', whereby the exerciser uses the numbers and verbal anchors on the Borg scale alongside his/her sense of effort to adjust their exercise output to match a pre-assigned value. Again, a body of research has confirmed the validity and reliability of RPE utilised in this manner in a number of exercise modes such as treadmill (Dunbar *et al.,* 1992; Eston *et al,.* 1987; Glass *et al.,* 1992; Kang *et al.,* 2003), field running (Chow & Wilmore, 1984; Ceci & Hassmen, 1991), cycle ergometry (Kang *et al.,* 1998, Hartshorn & Lamb, 2004; Kang, Chaloupka, Biren, Mastrangelo, & Hoffman, 2009), rowing ergometry (Marriott & Lamb, 1996), arm ergometry (Goosey-Tolfrey, Lenton, Goddard, Oldfield, Tolfrey, & Eston, 2010) and swimming (Green, Michael & Solomon, 1999). Recently a novel application of the production procedure has been developed examining the merit of applying a sub-maximal *perceptually-regulated exercise test* (PRET) to the prediction of maximum oxygen uptake during cycle ergometry (Eston, Lamb, Parfitt & King, 2005). This small-scale study ($n$ = 10) showed that participants' $\dot{V}O_2$max predicted from oxygen uptake values recorded during the PRET were, at worst, within 6 $ml \cdot kg^{-1} \cdot min^{-1}$ of actual values. Relative to other sub-maximal methods of prediction, this finding was encouraging and led to subsequent studies examining the predictive success of the cycle PRET when different lengths of exercise bouts were employed (Eston, Faulkner, Mason &

Parfitt, 2006), among active versus sedentary male and female populations (Faulkner, Parfitt, & Eston, 2007), and when a discontinuous protocol was used (Eston, Lambrick, Sheppard, & Parfitt, 2008).

The following programme of research aims to build on the work of Eston and colleagues to develop further the PRET technique and test its integrity. The thesis initially presents a review of the evidence on the validity and reliability of the Borg RPE scale when used to regulate exercise intensity in healthy and unhealthy adults. To-date, no scholarly publication has synthesised the body of knowledge on this specific application of Borg's RPE scale. Subsequently, four studies were completed to investigate the effects of different methodological variations on the predictive capabilities of the PRET, including an examination (for the first time) of its efficacy among heart failure patients (Study 4).

Study one re-visited the validity and reliability of the PRET technique utilising a modified protocol of differing durations (2 and 4 min bouts), with revised instructions and placing the graded exercise test (GXT) as the final trial during cycle ergometry. Placing the GXT first exposes participants to the full perceptual range, a practice which would not usually be afforded outside the laboratory and one which may falsely enhance the reliability and validity of the PRET owing to familiarisation. To-date, all studies have had participants regulating exercise intensity at RPE levels 9 (Very light), 11 (Light), 13 (Somewhat hard), 15 (Hard, heavy) and 17 (Very hard) followed by an extrapolation to either RPE 19 or 20 (Maximal exertion). Following a review of the data from Study 1, an RPE of 17 was

considered too strenuous for the types of populations this test was intended (sedentary and those taking cardiac-related medications), and subsequent studies were conducted on participants that exercised to an upper intensity of RPE 15 (Studies 2-4). This thesis also contains the first study to investigate the utility of the PRET during treadmill exercise (Study 2), which was a logical progression given that walking is the predominant mode of exercise for most people. Finally, on the basis that all the papers published on the PRET had alluded to its potential value with clinical populations, where heart rate response to exercise is often affected (e.g. by medication) and precludes the use of predictive HRmax equations, Study 4 investigated the efficacy of the PRET for predicting $\dot{V}O_2$peak in a beta-blocked population of heart failure patients.

# Chapter 2

# Review of Literature

## 2.1 The use of Borg's Rating of Perceived Exertion (RPE) Scale for regulating exercise intensity in adults

### 2.1.1 Introduction

Perceived exertion is the feeling of how heavy or strenuous a physical task is (Borg, 1998, p. 8). The concept of perceived exertion emanated in the 1950s from an interest in the possible relationship between an individual's subjective judgement of their working capacity and objective measurements of that capacity (Borg, 1998). To explain the response to an exercise stimulus on the perception of effort, Borg (1970) proposed an integrative model termed the 'three effort continua', consisting of perceptual, physiological and performance. Figure 2.1 illustrates this model, showing the exerciser or 'observer' who is performing a certain physical task (in this case rowing). The aim is to try to identify different levels or zones of subjective intensities, such as preferred levels, training zones and stress levels (Borg, 1998, p. 6).

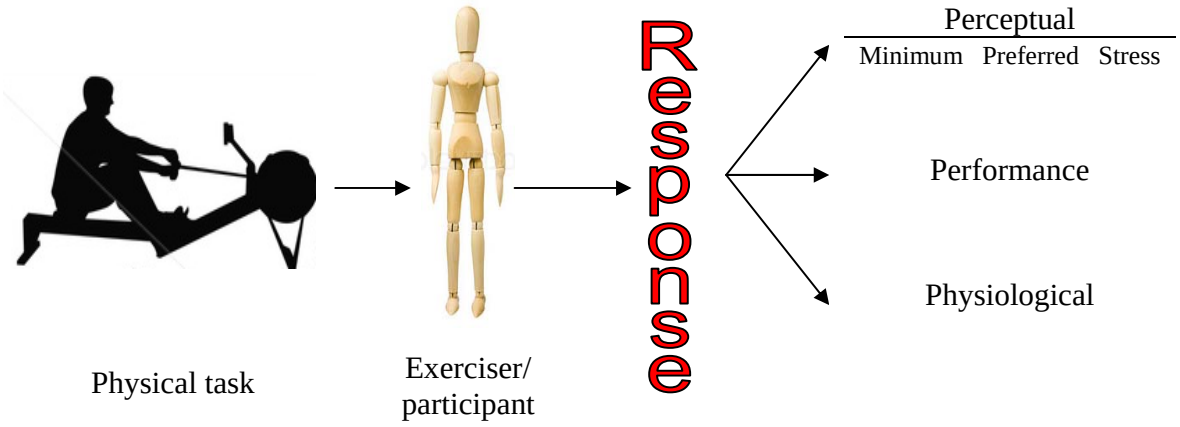


**Figure 2.1.** The three effort continua: perception, physical and performance (modified from Borg, 1998, p. 6)

The stimulus (physical task) interacts with the situation and the exerciser, eliciting a response in each of the continua; the intensity varies in all continua from minimum through to maximal intensity. The continua are described as follows:

### 2.1.2 Perceptual continuum

Perception plays a fundamental role in a person's behaviour and how situations are adapted to. The key starting point is with respect to an individual's subjective experience and reflecting on past knowledge of stressful situations, for example, exercise tasks or situations. It is primarily based on sensations emanating from the periphery, skin, muscles, joints and cardio-respiratory system.

### 2.1.3 Performance continuum

The situational characteristics of an exercise performance, such as the intensity, mode and environment, have an effect on the interplay between the perceptual and physiological continuums and consequently the individual's interpretation of the perception of effort (Borg, 1977). As depicted in Figure 2.1, the exercise task (represented by the rowing ergometer) interacts with the exerciser, which subsequently leads to a certain response in each of the three continua. The performances that are the easiest to define (and also measure) are maximal performances, for example, maximum workload or quickest time to complete a mile (Borg, 1998, p. 6).

### 2.1.4 Physiological continuum

In contrast to the variables connected with the perceptual continuum, the physiological continuum contains measures that are easily measured and regularly collected in exercise physiology laboratories, such as heart rate, oxygen uptake, blood and muscle lactate, ventilation and respiration rates and catecholamine excretion, to name but a few (Borg, 1998, p. 6). An important point to note is that the growth functions of these variables are not the same; some are linearly related (e.g. heart rate and $\dot{V}O_2$) to the stimulus intensity (e.g. Watts), while others (e.g. lactate concentration) are non-linear (positively accelerating). Due to this it is not easy to know how to integrate or weight them to predict performance successfully. This is where perceived exertion has advantages as it integrates many cues and emphasises the most important ones, which may provide a solution to this problem (Borg, 1998, p. 6).

The concept of perceived exertion mainly refers to heavy muscular work which involves large amounts of strain on the cardiovascular, musculoskeletal and pulmonary systems and is therefore closely related to the concept of exercise intensity. An important point to make is that perceived exertion *per se* is not a measure; a scale must exist on which to rate it. The first studies by Borg and Dahlstrom (1959; 1960) addressed the issue of how perceived exertion varied as a function of changes in physical workload. Specifically, they dealt with perceptual judgements of effort and pedal resistance during short-term (lasting a few seconds to a few minutes) exercise on a cycle ergometer and then during work of longer

duration (lasting several or many minutes). The knowledge gained from these early experiments led Borg to construct the Rating of Perceived Exertion (RPE) scale (Borg, 1962; 1970; 1985).

This scale is a well-established tool that is commonly used (in addition to objective physiological markers) for quantifying the intensity of exercise and for prescribing exercise intensity in healthy adults and some patient groups (Bird & Davidson, 1997; ACSM, 2010). The RPE scale is most often used as a passive response measurement (consequently termed *estimation* mode) during graded exercise tests (GXTs) or other forms of physical activity whereby the exerciser is presented with the 6-20 scale and at a specific moment indicates a rating that reflects how hard the exercise feels. A large body of research has demonstrated how such RPE ratings vary in line with changes in a number of physiological (e.g. heart rate, oxygen consumption, blood lactate) and physical (e.g. power output, speed) markers of intensity (Borg, 1998). This relationship can be reflected readily by high correlations ($r > 0.90$) being observed between ratings and the objective indicators of effort during a GXT (Borg, 1985). Yet, it is not the intention of this review to confirm the reliability and validity of perceived exertion during estimation mode, as this is well established (Carton & Rhodes, 1985; Hampson, Gibson, Lambert & Noakes, 2001; Chen, Fan & Moe, 2002; Groslambert & Mahon, 2006). Instead, this review will evaluate the evidence for its use in regulating exercise intensity by active participant control. This less common, but increasingly more popular application of RPE involves the self-adjustment, or *production* (utilising

RPE as the independent variable) of exercise intensities prescribed as fixed RPE levels, such as 9, 13 or 15.

Unlike estimation mode, during production mode the individual is required to be active in setting or adjusting the exercise intensity to match a pre-set level on Borg's RPE scale. Typically, following a period of time allocated for fine tuning (adjustment), the exerciser settles on an intensity that equates to the prescribed value and continues at that for a set amount of time. The drive for this application of RPE (regulating exercise intensity) came from the need for a simple way to sustain adherence to an exercise program that would be considered both safe and be beneficial to health and fitness (Williams & Eston, 1989). Numerous studies in the past 25 years have provided evidence for the validity of using RPE during production mode to regulate exercise intensity in a range of exercise modalities, such as treadmill exercise (Dunbar *et al.* 1992; Eston *et al.* 1987; Glass *et al.* 1992, Kang *et al.* 2003), field running (Chow & Wilmore, 1984; Ceci & Hassmen, 1991), cycle ergometry (Kang *et al.,* 1998, Hartshorn & Lamb, 2004; Kang *et al.,* 2009), rowing ergometry (Marriott & Lamb, 1996), arm ergometry (Goosey-Tolfrey *et al.,* 2010), swimming (Green, Michael & Solomon, 1999) and wheelchair exercise (Ward *et al.,* 1995). RPE used in this way ("perceptual regulation") has several advantages in that the approach is inexpensive, easy for the exerciser to learn and requires no physiological monitoring or interruption of activity (Kang *et al.,* 1998). It is also not affected by medical conditions, such as atrial fibrillation, chronotropic and inotropic medications (e.g. β-blocker therapy) or hot environments, which alter the normal heart rate-exercise intensity relationship (Kang *et al.* 1998; Eston &

Connolly, 1996). Moreover, since 2005 (Eston *et al.,* 2005) an exciting development has emerged in which the efficacy of *perceptually-regulated* exercise for predicting exercise capacity has been explored. The merit of such an application lies in its simplicity and that the individual controls their own protocol, unlike traditional protocols which have to be administered by the investigator following questioning about the exerciser's training status and likely capacity, which might involve a certain degree of error.

At present, there exists no scholarly publication synthesising the body of knowledge among healthy and unhealthy adults on the validity and reliability of RPE applied in production mode. Therefore the aim of this section of the thesis is to review the evidence and provide the basis for which exercise practitioners and the scientific community can reach an informed decision on the efficacy of perceptually-regulated exercise in adult populations.

### 2.1.5 Reliability and validity of RPE in production mode

Enquiries into whether exercise intensity can be controlled via RPE to produce a target metabolic demand started in the 1980s (Smutok *et al.,* 1980) and prompted a flurry of further validation studies (Chow & Wilmore, 1984; Ceci & Hassmen, 1991; Glass *et al.,* 1992; Dunbar *et al.,* 1992; Zeni *et al.,* 1996; Marriott & Lamb, 1996; Eston & Thompson, 1997; Buckley *et al.,* 2000; Goosey-Tolfrey *et al.,* 2010). These studies, involving different modes of exercise, have typically used an *estimation-production* paradigm whereby an individual estimates his/her perception of effort during a GXT and then in a separate trial produces an exercise

intensity based on these previous exertions. Typically, the success of this approach has been quantified by investigating the associations of corresponding measures of oxygen uptake ($\dot{V}O_2$), heart rate, power output or pace between the estimation and production protocols. High correlations (> 0.80) between the estimation and production responses were presumed to reflect equivalency, and thereby confirm the validity of the RPE production mode. However, as discussed more fully later in this review, such a statistical approach is not appropriate since it does not actually quantify the degree of within-subject variation (error) between the protocols and might mis-represent the issue of validity.

Alternatively, some studies have adopted a *production-only* paradigm, in which no reference to a prior estimation trial is made and individuals simply adjust the exercise intensity to match experimenter-assigned values (Ceci & Hassmen, 1991; Zeni *et al.,* 1996; Buckley *et al.,* 2000; Hartshorn & Lamb, 2004). Again, the validity of this process has often been addressed in terms of the association between the physiological measures of intensity and the assigned RPE levels. Alongside this, researchers have also tended to test for statistical bias between the mean responses to the prescribed RPE levels and argued that if higher values accompany higher RPE levels, then the validity of such perceptual regulation is established. On an individual basis, however, such sample statistics can mask the existence of considerable deviation from the trend and are incomplete without a measure of the within-subject variation.

The reliability (or reproducibility) of responses elicited by exercisers employing RPE in the production mode has been scrutinised via test-retest designs involving two or three repeated trials, separated usually by a few days to a week (Myles & Maclean, 1986; Bayles, Metz, Robertson, Goss, Cosgrove, & McBurney, 1990; Kang *et al.,* 1998; Buckley, Eston & Sim, 2000; Hartshorn & Lamb, 2004). Arguably, if such consistency cannot be demonstrated, then the validity of perceptual regulation has to be questioned. Of note here is that a learning or practice effect is, intuitively, more likely to occur than in an estimation paradigm, since the task of perceptual regulation is more complex. Some investigators have sought to account for this (Buckley *et al.,* 2000; Hartshorn & Lamb, 2004), along with adopting the kind of statistical analysis that was often absent from the validation studies mentioned above. Specifically, such studies have appropriately used a measure of *absolute* reliability, the 95% limits of agreement technique (Bland & Altman, 1986) in preference to relative measures, such as the bivariate correlation coefficient.

### 2.1.6 Treadmill and field running

The original investigation into the regulation of exercise intensity utilising Borg's RPE scale during treadmill exercise was conducted by Smutok *et al.* (1980) on 10 males who provided Borg RPE values at speeds of 4.7, 6.5, 9.7, 11.3 and 12.9 $km \cdot h.^{-1}$ Participants were then asked to perform a further two trials based upon the RPE values given in the initial estimation trial, by regulating the velocity of the treadmill. The results indicated that the validity across the trials for HR ($r$ >

0.85), $V_E$ ($r$ > 0.86), $\dot{V}O_2$ ($r$ > 0.82) and speed ($r$ > 0.85) was good, however the reliability was seen to be poor for HR ($r$ = 0.52) and $\dot{V}O_2$ ($r$ = 0.48) at RPE 10 and below, and in general at heart rates less than 150 beats·min$^{-1}$ (80% of maximal HR). Similar observations that better congruence occurred at higher RPE levels were also reported by Eston *et al.* (1987) and Bayles *et al.* (1987). A summary of production mode studies conducted with treadmill and field running is presented in Table 2.1 (p. 24).

In the Eston *et al.* study (1987) 28 healthy men and women completed a maximal oxygen uptake ($\dot{V}O_2$max) test and were then asked to run at three intensities which they perceived to be 9, 13 and 17 on the Borg scale in that order. The analysis of the relationships between RPE and HR and percent $\dot{V}O_2$max in both trials revealed similar correlation coefficients ($r$ = 0.84 – 0.91 and $r$ = 0.88 – 0.93 for the GXT and production trials, respectively), but in particular that the production of effort was reasonably accurate at moderate-high levels of RPE (13 and 17) and less so at the lower level of 9. Whilst this latter conclusion was apparently based only on descriptive statistics, the study's data did demonstrate the appropriateness of regulating exercise intensity at RPE 13 as this equated approximately to 70% $\dot{V}O_2$max, which is within the American College of Sports Medicine's (2010) recommended 50–85% $\dot{V}O_2$max. Similar equivalents were subsequently confirmed by other researchers (Zeni *et al.,* 1996; Katsanos *et al.,* 2001; Glass *et al.,* (1992); Green *et al.,* 2002), and most recently in Study 2 contained within this thesis (Chapter 4). It should be noted that the 59–84%

$\dot{V}O_2$max range elicited at RPE 13 in the Eston *et al.* (1987) paper would not be suitable for clinical populations without additional monitoring (e.g. of heart rate).

In support of the findings of higher validity at higher intensities, Glass *et al.* (1992) reported that participants who regulated their exercise intensity using speed only on a treadmill were on average, within one MET (3.5 $mlO_2 \cdot kg^{-1} \cdot min^{-1}$) and 4 $beats \cdot min^{-1}$ of the values elicited at 75% heart rate reserve (HRR) in a prior GXT estimation trial. Although percent $\dot{V}O_2$peak was significantly higher during the GXT (69 ± 10.3%) compared to the production trial (64 ± 12.4%), this was still within suggested guidelines and was deemed to have no real practical/clinical significance. In contrast, Dunbar *et al.* (1992) observed significantly lower ($p$ < 0.01) HR at 70% $\dot{V}O_2$max during a production trial compared to a GXT, but no difference at 50% $\dot{V}O_2$max. In this case, the data supported the use of RPE for regulating exercise at a moderate intensity, rather than at a high intensity. More generally, several other studies have supported the notion that heart rate in production mode is lower than in estimation (Chow & Wilmore, 1984; Dunbar *et al.,* 1992; Glass *et al.*,1992; Hull & Potteiger, 1999; Kang *et al.,* 2003).

What might explain the inconsistencies in the literature is that some studies have compared a graded GXT (in estimation mode) with a production trial of varying speeds on a level treadmill (Glass *et al.,* 1992; Dunbar *et al.,* 1992) whilst others have altered both treadmill speed and gradient (Eston *et al.,* 1987; also see Study 2 of this thesis). The variability of gradient could have affected the

sensations being assimilated by the exercisers in their overall perception of the exercise (e.g. increased sensations in the legs). Indeed, Green, Crews, Bosak, & Peveler, (2002) observed that when this factor (gradient at 0% and 10%) was considered at two exercise intensities (50% and 70% $\dot{V}O_2$max) in GXT and production trials, it had a notable bearing on the HR and $\dot{V}O_2$ responses. That is, in the 50% condition, mean HR and $\dot{V}O_2$ in the 10% gradient production trial were not significantly different ($p$ > 0.05) to those in the GXT, whereas they were significantly lower in the level (0% gradient) trial. That this pattern of responses was replicated in the 70% $\dot{V}O_2$max condition suggests that, with treadmill running at least, the physiological responses to estimation and production trials are likely to be comparable only when the relative intensity of the latter is higher, or an incline is introduced.

An alternative approach to assessing the suitability of regulating exercise intensity via perceived exertion was adopted by Chow & Wilmore (1984) who compared how well groups of sedentary males could maintain treadmill walking and running in a training heart rate range (60-70% HRR) whilst regulating their exercise in response to one of three feedback conditions; radial or carotid artery pulse rate, the RPE scale, and no feedback. The authors reported favourably that the time spent in the training zone on the basis of the RPE feedback (48.5%) was similar to that in the pulse rate condition (55.3%), and superior to the control condition (24.5%). However, with respect to RPE, their data meant that the exercisers were not at an appropriate intensity 52.5% of the time, which is not

trivial, and would be of particular relevance for other individuals beginning an exercise programme or with a clinical diagnosis. It should be noted that the investigators did not provide the control group with the learning trials that the two experimental groups received, making the internal validity of the experimental design suspect. Additionally, that the pulse rate group were reliant on self-administered palpation raises a doubt over the accuracy of the HR values determined.

Perceptually-regulated exercise on a treadmill has been shown to produce significantly higher rates of energy expenditure than other modes of exercise (Zeni *et al.,* 1996). In this study, 13 participants underwent a four-week habituation period (twice a week) to become familiar with the RPE scale and exercise on a variety of exercise machines (treadmill, cycling, rowing, Airdyne, cross country skiing simulator and stair stepper). Participants then completed an exercise protocol on each of the machines, regulating the exercise at RPE values 11 (fairly light), 13 (somewhat hard) and 15 (hard). The treadmill induced significantly higher ($p < 0.05$) rates of energy expenditure and HR at each RPE level than all the other exercise machines, but blood lactate levels that were lower than most. Of critical note, however, was the paper's lack of descriptive statistics (other than those suggested by somewhat vague figures) and that the study did not use the most current (1985) Borg scale.

An interesting study by Stoudemire, Wideman, Pass, McGinnes, Gaesser, and Weltman (1996) investigated whether blood lactate concentration could be

regulated in the same manner as HR and $\dot{V}O_2$ by RPE. Nine participants completed two perceptually-regulated, randomly assigned 30-minute treadmill trials at the RPEs associated with 2.5 mM and 4.0 mM lactate thresholds previously established during an incremental GXT. During both trials the corresponding $\dot{V}O_2$ values were not significantly different throughout to those attained during the GXT, but the HR responses were inconsistent. That is, the HRs were lower than in the GXT and increased over time. Moreover, whilst the selected speeds at the less intense trial matched those in the GXT, they did not in the 4.0 mM trial, being lower on average. These findings suggested that participants were using their perception of exertion to down-regulate the exercise intensity (speed) appropriately in order to maintain the $\dot{V}O_2$ levels. As HR was continually rising throughout the 30 minutes however, indicates that RPE and HR may be 'uncoupled' and that HR might not be the primary cue for interpreting sensations (Stoudemire *et al.* 1996).

The majority of running-based investigations have been conducted in a laboratory setting (which may be transferable to a fitness centre), but only a few have investigated the production of exercise intensities in an ecologically valid 'field' environment (Whaley & Forsyth, 1990; Ceci & Hassmen, 1991). Whaley and Forsyth (1990) set out to determine whether exercise intensity could be regulated by RPE alone or alongside HR during one week of interval training (on four days) on an indoor running track. Thirty two men completed a maximal treadmill test to determine a target heart rate of 75% HRmax prior to being randomly assigned to one of four groups utilising heart rate, or heart rate and RPE, or RPE alone, or

control (no feedback) to guide their intensity regulation. Participants were then given a learning trial (allowing each to experience a brief period at steady-state at their target heart rate) which involved following a pacer who controlled the running speed at 75% HRmax. Thereafter, they were required to regulate the intensity at 75% HRmax using the assigned feedback (HR, HR plus RPE, RPE or control) over four training days with four regulation trials per day. Whilst all four groups exceeded the target heart rate on days two to four, those using heart rate feedback (HR and HR plus RPE) were more accurate at regulating exercise intensity at the target heart rate (75% HRmax) than the groups not using heart rate (except control, T2). These data are presented in Figure 2.2 (though no actual values were reported in the original paper).

Additionally, it was found that the participants using RPE as feedback tended to be more accurate in replicating the *running speed* from the paced trial when compared to the non-RPE groups (pace deviation scores of 3.7 ± 4.6 versus 9.5 ± 3.4 $m \cdot min^{-1}$), though this difference was not statistically significant. However, the RPE group was no more accurate than the control group on days one, three and four with respect to achieving its target heart rate. It was concluded that utilising RPE as the feedback mechanism to regulate exercise was of little benefit, although, it must be emphasised that this study utilised interval training and the results may not be applicable to continuous training programs.

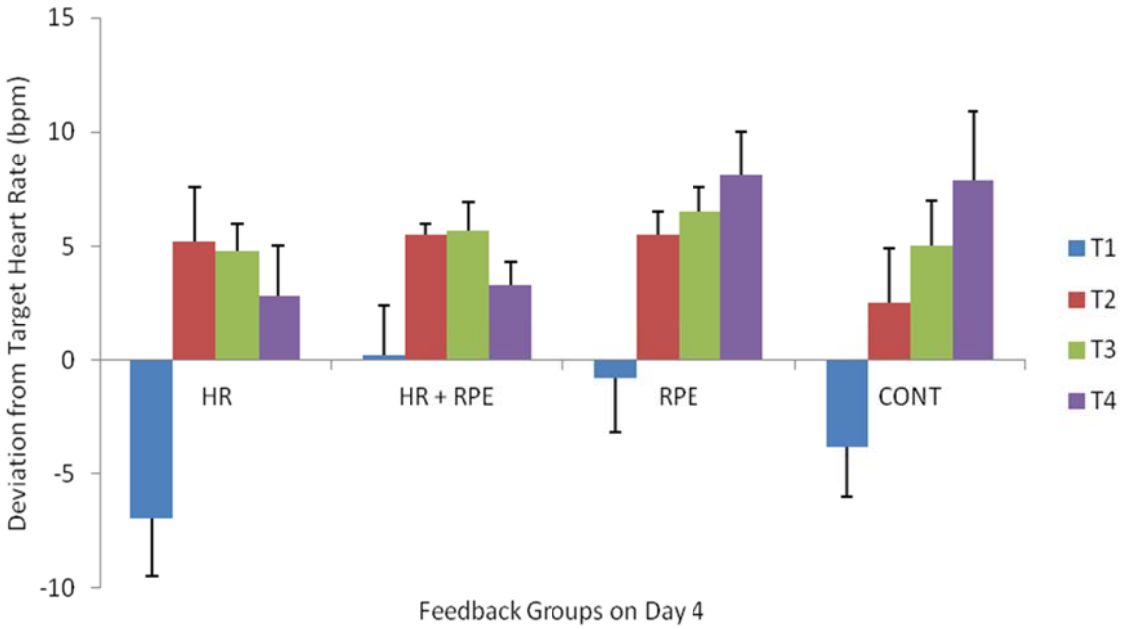


**Figure 2.2.** Differences among feedback groups showing deviation from target heart rate on training day four (re-drawn from Whaley & Forsyth, 1990)

On a similar theme, but producing very different findings Ceci and Hassmen (1991) investigated self-regulated exercise at three RPE levels; 11 (light), 13 (somewhat hard) and 15 (hard) in treadmill and outdoor track running. Objective markers of effort (velocity, HR, and blood lactate) recorded during the field exercise were significantly higher ($p < 0.001$) than on the treadmill, at each RPE level. Also, it appears from the data presented that a reduction of two RPE levels from the treadmill to the field exercise, especially for RPE 13 and 15, yielded corresponding reductions in velocity and HR. These findings lead the authors to recommend that for unhealthy or clinical populations to stay within the lower intensities of the ACSM (2010) guidelines that training intensity should be kept at (or below) RPE 13 in the field and RPE 15 during treadmill exercise. Importantly, it was concluded that

regulating exercise intensity via perceived exertion functioned well under the conditions of this study.

Finally, in a rather unique study the robustness of the validity of perceptual exercise regulation was examined by Hull & Potteiger (1999), who provided a visual distraction to participants during treadmill exercise. Having displayed a high action video, a low action video with no audio, and a control condition during production exercise, Hull & Potteiger observed that the mean HR responses were almost identical (158–159 beats·min$^{-1}$), inferring that a visual distraction did not alter the ability of the participants to regulate their exercise intensity.

**Table 2.1** Summary of treadmill and field running studies in RPE production mode.

<table>
<tr><th>Study</th><th>Participants</th><th>Exercise mode</th><th>Protocol</th><th>Key Findings/Interpretations</th></tr>
<tr><td>Smutok, Skrinar,& Pandolf (1980)</td><td>10 males</td><td>Treadmill</td><td>Treadmill, Ex at 4.7, 6.5, 9.7, 11.3 & 12.9 km/h obtained RPE ($T_1$). Then production mode at the RPE provided for each speed ($T_2$). Then repeated ($T_3$). Speed, hr and $VO_2$ measured.</td><td>Validity – good ($T_1 – T_2$): r values:<br><table><tr><td></td><td>speed</td><td>HR</td><td>$V_E$</td><td>$VO_2$</td></tr><tr><td>$T_1$</td><td>0.83</td><td>0.87</td><td>0.86</td><td>0.87</td></tr><tr><td>$T_2$</td><td>0.85</td><td>0.87</td><td>0.90</td><td>0.81</td></tr><tr><td>$T_3$</td><td>0.85</td><td>0.85</td><td>0.90</td><td>0.82</td></tr></table>Test – retest ($T_2 – T_3$):<br>speed r = 0.74 – 0.94,<br>HR r = 0.52 – 0.92 sig diff at 7.9 km/hr.<br>$VO_2$ r = 0.48 – 0.94 sig diff at 7.9 km/hr.<br>HR & $VO_2$ only sig above RPE 10<br><br>N.B. Poor reliability in HR & $VO_2$ less than RPE 10, but speed OK</td></tr>
<tr><td>Chow & Wilmore (1984)</td><td>29 males<br>23.1 ± 3.6 yr<br><br>$VO_2$max 42.3 ± 5.9 ml/kg/min</td><td>Treadmill. Self-paced jogging</td><td>3 groups (HR, RPE & Control)<br>Target of subjects was to exercise between 60–70% $VO_2$max</td><td>HR groups exercised within this range 55.3% of the time, RPE grp 48.5% of the time and control 24.5%.<br><br>N.B. Mean HR lower in RPE group than in HR and Cont groups</td></tr>
<tr><td>Dishman, Patton, Smith, Weinberg & Jackson (1987)</td><td>24 males<br>27.7 ± 3.9 yr<br><br>36.9 ± 4.1 ml/kg/min (‘Average’)</td><td>Treadmill</td><td>3 x Balke GXT control, HR and HR + RPE feedback.<br>Followed by field trial (3 x 800 m) jog to achieve target HR</td><td>No differences between groups (combined HR & RPE) in reaching target HR.<br><br>Learned to use scale and better at higher levels.</td></tr>
<tr><td>Bayles, Metz, Robertson, Goss, McBurney & Cosgrove (1987)</td><td>30 males<br>18-25 yr</td><td>Treadmill</td><td>3 Groups<ul><li>Practice with feedback</li><li>Practice without feedback</li><li>Control</li></ul></td><td>More accurate with practice and feedback and also after a practice session. Also better at higher intensities.</td></tr>
</table>

| | | | | |
|---|---|---|---|---|
| Eston, Davies & Williams (1987) | 16 men & 12 women,<br>21.3 ± 3.9 yr<br>23.2 ± 4.8 yr<br><br>Relatively fit | Treadmill | Estimation mode $VO_2$max, production mode @ 9, 13 & 17. | Linear regression for both modes. **Men** = RPE:$VO_2$ est r = 0.91; prod r = 0.93; RPE:%HRmax est r = 0.87; prod r = 0.90.<br><br>**Women** = RPE:$VO_2$ est r = 0.87; prod r = 0.89; RPE:%HRmax est r = 0.84; prod r = 0.88.<br><br>Support for validity, but not assessed at each RPE individually.<br>Better at higher RPE levels |
| Bayles, Metz, Robertson, Goss, Cosgrove & McBurney (1990) | 30 male students<br>21.3 ± 2.1yr<br><br>'Good fitness' | Treadmill and Outdoor track | Validity & reliability with Borg training<br>$VO_2$max then 3 groups PF, PWOF & Control, 4 repeated measures.<br>$VO_2$max, T1 = est, T2–4 production.<br><br>Practice with feedback | Calculated percentage inaccuracy scores (%IS). Overall 15% diff<br>Speed = accuracy ↑ PF but ↓ control<br>Trial 3-4 all gps same %IS<br>HR = no sig diff; mean diff 7%<br>$VO_2$ = no sig diff; mean diff 12%<br><br>Supports validity, but accuracy better at 60% & 80% than 40%. Odd speed %IS > HR & $VO_2$ %IS<br>Practice and feedback<br>NOT normal Borg scale (modified) |
| Whaley & Forsyth (1990) | N = 32 men<br>23.6 ± 3.2 yr<br><br>Sedentary | Treadmill versus field running | $VO_2$max then :<br>4 groups, HR, RPE, HR + RPE & Cont. | HR & HR + RPE sig more accurate than those not using RPE.<br>RPE groups no more accurate than control<br><br>Little benefit |
| Ceci & Hassmen (1991) | N= 11 males<br>42.9 ± 11yr<br>Physically active | Treadmill versus field running | 2 x treadmill and 2 x running track at RPE 11, 13 & 15 | Reliability good r=0.9 and above<br>Field = RPE 13 appropriate for intensity<br>Treadmill = RPE 15 and below correct intensity |
| Dunbar, Robertson, Baun, Blandin, Metz, Burdett & Goss (1992) | N = 17<br>17-35 yr<br><br>35-65 ml/kg/min | Treadmill & Cycle | RPE equivalent to 50 & 70% $VO_2$max from GXT | Cycle more accurate<br>Treadmill not valid at 70%<br><br>Validity supported. |

| | | | | |
|---|---|---|---|---|
| Glass, Knowlton & Becque (1992) | 15 men<br>22.4 ± 3.1yr<br>Active | Treadmill | GXT then 10 min of exercise at RPE equivalent of 75% HRR from GXT just altered speed | After 6 min within 4 beats of target HR<br>No diff $VO_2$<br>Valid & accurate |
| Dunbar, Goris, Michieli & Kalinski (1994) | N=9<br><br>untrained | Treadmill & Cycle | 2 x cycle<br>2 x Treadmill<br>@60% $VO_2$max RPE from a GXT | No sig diff except between 2nd cycle, this was diff from target $VO_2$<br>Good on treadmill but lower on cycle than target |
| Zeni, Hoffman & Clifford (1996) | 8 men; 5 women<br><br>35 ± 4yr<br>Healthy | x country skiing,<br>Rowing<br>Stair stepper<br>Treadmill<br>Cycle | eight habituation sessions<br>3 stages on each machine of 5 mins at RPE 11, 13 & 15 | Treadmill superior for energy expenditure<br><br>All modes of exercise met $VO_2$ ACSM guidelines except cycle between RPE 13-15<br>All met %HR ACSM guidelines except airdyne at RPE 11 |
| Stoudemire, Wideman, Pass, McGinnes, Gaesser & Weltman (1996) | n = 9, (5 males, 4 females)<br>25 ± 4 yr<br>Healthy | Treadmill | GXT and lactate threshold protocol, then 2 randomly assigned trials at RPE associated with 2.5mM and 4.0mM for 30mins | RPE can be used to regulate exercise intensity close to criterion levels of 2.5mM and 4.0mM as assessed via $VO_2$, although HR was sig lower at 4.0mM throughout. |
| Byrne & Eston (1998) | n = 10<br>young healthy | Treadmill | GXT then production trial at 11, 13, 15 and 17 | Support, but exercise intensity slightly lower in prediction trial than estimation. |
| Katsanos, Cheuvront, Haymes (2001) | 11 males<br>26.6 ± 1.3 yr<br><br>52.6 ± 1.6 ml/kg/min<br>Healthy | Cycling & Treadmill walking | GXT then cycling and walking at RPE 11, 13 + 15 | Cycling > energy expenditure than walking at RPE 11<br>No sig diff at RPE 13<br>Walking > energy expenditure than cycle at RPE 15<br>correct intensity to meet ACSM guidelines |
| Green, Crews, Bosak & Peveler (2002) | 13 males<br>13 females<br>23 ± 2.6 yr<br>55.6 ± 11.8 ml/kg/min<br>Healthy | Treadmill | Bruce GXT then individually prescribed RPEs at 50% and 70%$VO_2$max in production mode at 0% and 10% grade. | At 50% $VO_2$max HR and $VO_2$ not sig diff between est and prod at 10% incline, but were sig lower at 0% in prod.<br>At 70% $VO_2$max HR and $VO_2$ not sig diff between est and prod, but were sig lower at 0% in prod mode. |

Note: est = estimation trial; prod = production trial

### 2.1.7 Cycle ergometry

The 11 publications to-date that have applied RPE in production mode (see Table 2.3, p. 32) during laboratory-based cycling ('cycle ergometry') commenced with a study by Myles & Maclean (1986) who set out to ascertain whether their protocol could substitute the more commonly used estimation protocol. Eight male and female adults undertook two cycle ergometer tests on separate occasions, one in estimation mode involving nine power outputs (80–200 watts) administered every minute in a random order at the end of which they rated their perceived exertion, and the other in production mode, where they were given nine RPE values to achieve, starting with RPE 13 (somewhat hard) and the remainder ranging from 11 (slightly hard) to 17 (very hard). These two trials were conducted twice, once from a rested state and once following a one-hour run. Linear regression of RPE and power output revealed no significant difference between the regression coefficients of the estimation ($r^2$ = 0.88 ± 0.08) and production ($r^2$ = 0.92 ± 0.05) trials. Moreover, the relationship between RPE and power output before and after the run did not change (no data provided). Also, when the RPE corresponding to 150 W was substituted into the regression equation for the estimation trial, it produced a power output of 152 ± 15 W, which was not statistically different. It was concluded that the production protocol could substitute the estimation protocol and that a particular advantage of this was that the participants could select from a wide range of power outputs during the production trial (as they were in control), but have only 15 category ratings to choose from during the experimenter-controlled estimation trial. In support of this equivalence,

Dunbar *et al.* (1992) reported only a 1.6% mean difference in $\dot{V}O_2$ between estimation and production cycling protocols at target exercise intensities of 50% and 70% $\dot{V}O_2$max. These results are somewhat supported by several studies (Eston & Williams, 1988; Dunbar *et al.,* 1994; Zeni *et al.,* 1996; Eston & Thompson, 1997; Kang *et al.,* 1998, Buckley *et al.,* 2000 & Kang *et al.,* 2009) but not all (Hartshorn & Lamb, 2004). Notably, not all studies have supported the use of RPE in production mode across the full perceptual range, especially in the first trial (Eston & Williams, 1988; Kang *et al.,* 1998), suggesting a distinct role for the provision of practice or familiarization trials.

On this theme, Eston & Williams (1988) had 16 healthy males and females perform a GXT followed by three identical production protocols at RPE 9, 13 and 17 (in that order) 5 - 7 days apart. Albeit simply based on correlation analysis of the $\dot{V}O_2$ and HR responses across trials, there was a marked trend towards a better consistency of responses ('reliability') as the exercise intensity increased, with a low coefficient ($r$ = 0. 26) for $\dot{V}O_2$ at RPE 9 between trial one and two, and higher coefficients ($r$ = 0.64 and $r$ = 0.92) at RPE 13 and 17, respectively. The third production trial improved the reliability of the lowest intensity (RPE 9), with correlations rising to 0.83 and 0.77 for $\dot{V}O_2$ and HR, respectively. An improvement was also observed at RPE 13, but correlations were consistently high in all trials at RPE 17. Such practice effects were later supported by Byrne & Eston (1997) and Buckley *et al.* (2000). An important benefit of practicing perceptually-regulated exercise was highlighted by Zeni *et al.* (1996) who provided no less than eight

practice sessions before participants undertook a perceptually-regulated cycling trial, and found that the mean HR at RPE 13 (approximately 70% HRmax) and 15 (approximately 77 %HRmax) were within the ACSM's (2010) recommended guidelines (60-90% HRmax) for exercise training. Interestingly, the mean $\dot{V}O_2$ produced was marginally lower (approximately 48% $\dot{V}O_2$max) than the recommended range (50–85% $\dot{V}O_2$max) for RPE 13.

As with treadmill exercise, HR in production mode cycling has tended to be 10–15% lower than in estimation cycling (Chow & Wilmore, 1984; Dunbar *et al.,* 1992; Glass *et al.,* 1992; Kang *et al.,* 1998; 2003). Likewise, in the studies by Kang *et al.* (1998; 2009), power output (PO) was reported to be under-produced during cycling, though given that $\dot{V}O_2$ was not significantly different, this is at odds. On closer inspection it transpired that the pedal rates during the estimation protocol were regulated at 60 revs·min$^{-1}$, whereas in the production mode no restriction was imposed, and participants were seen to have cycled at 70-71 revs·min$^{-1}$. Previous research has shown that faster cadences produce higher RPE (Hamer, Boutcher & Boutcher, 2005) and $\dot{V}O_2$ (Hagan, Weis & Raven, 1992; Kang *et al.,* 1992) values, so higher pedal rates meant a lower power output was produced to stay in the target metabolic ($\dot{V}O_2$) range. However, this cadence was still within the recommended range of 50–80 revs·min$^{-1}$ suggested by Marsh and Martin (1998), who demonstrated that an 'integrated overall' RPE in estimation mode is independent of cycling speed in this range at a given work rate. It is also argued that allowing participants to determine their own pedal frequency is necessary as it

resembles what would happen in a real-life exercise prescription scenario (Kang *et al.,* 2009). More generally, the apparent 'under-production' of effort during perceptually-regulated exercise has been attributed to the fact that the cognitive process (involving memory) is different to the process of estimating effort intensity during continuous exercise exertion (Noble, 1982; Eston *et al.,* 1987; Dunbar *et al.*, 1992; Byrne & Eston, 1998). This notwithstanding, it is has been noted that cycling facilitates better production accuracy than treadmill exercise at both 50 and 70% $\dot{V}O_2$max (Dunbar *et al.,* 1992).The researchers posited that this was owing to the enhanced localised muscular fatigue experienced during cycling that enabled participants to gauge better the intensity of the signals from the peripheral nervous system (Dunbar *et al.,* 1992). Also, the stable position of the participant on the cycle meant that he/she did not have to maintain balance and concentration (as on the treadmill) and would be afforded more attention to the RPE scale (Dunbar *et al.,* 1992).

Another factor considered with respect to the efficacy of perceptually-regulated exercise is that of the duration of the bout (Kang *et al.,* 2009). In their repeated measures design, 20 participants completed a cycle GXT to elicit RPE estimation responses at 50% and 75% $\dot{V}O_2$max, followed by four sub-maximal perceptually-regulated protocols of differing duration (20 and 40 min) and intensity equivalent to the RPE achieved at 50 and 75% $\dot{V}O_2$max from the GXT. Whilst their analysis confirmed the under-production of exercise intensity relative to the estimation trial data (as alluded to previously) at both $\dot{V}O_2$max intensities and at

both time points, there were no changes *between* the 20 and 40 minute bouts (see Table 2.2).

**Table 2.2** Average oxygen uptake ($\dot{V}O_2$), heart rate (HR) and Power Output (PO) between production and estimation trials (re-drawn from Kang *et al.* 2009)

| | **Estimation** | **Production** | |
|---|---|---|---|
| | | **20 min** | **40 min** |
| **50% $\dot{V}O_2$peak** | | | |
| **$\dot{V}O_2$ ml·kg$^{-1}$·min$^{-1}$** | 15.8 ± 0.6 | 14.2 ± 0.8 | 14.2 ± 0.8 |
| **HR (bpm)** | 130.1 ± 3.3 | 115.9 ± 4.3* | 119.7 ± 4.3* |
| **Power Output (W)** | 73.4 ± 5.0 | 56.3 ± 6.7* | 59.8 ± 6.4 |
| **75% $\dot{V}O_2$peak** | | | |
| **$\dot{V}O_2$ ml·kg$^{-1}$·min$^{-1}$** | 23.7 ± 1.0 | 22.1 ± 1.2 | 21.1 ± 1.0 |
| **HR (bpm)** | 156.6 ± 3.3 | 148.1 ± 5.1* | 149.3 ± 3.7* |
| **Power Output (W)** | 132.8 ± 8.3 | 101.5 ± 7.3* | 96.2 ± 6.3* |

Values are mean ± SE
* $p < 0.05$, estimation versus production

It was concluded that exercise duration has minimal impact upon the accuracy of using RPE to regulate exercise intensity, although it has to be questioned whether the difference in the durations was large enough and further research is warranted to investigate longer durations of exercise. It has been reported above that the reliability of regulating exercise utilising RPE during cycle ergometry has been shown to improve during repeated trials, after which it attains acceptable levels, even at a low intensity (Eston & Williams, 1988; Byrne &

**Table 2.3** Summary of cycle ergometry studies in RPE production mode.

| Study | Participants | Exercise mode | Protocol | Key Findings/Interpretation |
|---|---|---|---|---|
| Myles & Maclean (1986) | 4 male & 4 females<br>30.5 ± 4.4yr<br><br>Active (joggers) | Cycle ergometer | Validity & reliability<br>Est given 9 power outputs.<br>Prod given 8 RPEs between 11–17<br>Repeated | Mean power output est 152W and prod 150W.<br>No sig diff in regression coefficients; est r = 0.875 & prod r = 0.915.<br>Support provided. |
| Eston & Williams (1988) | 10 men & 6 women<br>21 – 62 yr | cycling | GXT then:<br>3 x cycle at 9, 13 & 17 in production mode | No sig diff (relative) between men and women<br>More reliable at higher intensities<br><br>Suggest practice improves |
| Dunbar, Robertson, Baun, Blandin, Metz, Burdett & Goss (1992) | N = 17<br>17-35 yr<br>35-65 ml/kg/min | Treadmill & Cycle | RPE equivalent to 50 & 70% $VO_2$max from GXT | Cycle more accurate<br>Treadmill not valid at 70%<br>Validity supported |
| Dunbar, Goris, Michieli *et al.* (1994) (Abstract) | N = 9<br><br>Untrained | Treadmill & Cycle | 2 x cycle<br><br>2 x Treadmill @60% $VO_2$max RPE from a GXT | No diff except in 2nd cycle, this was diff from target $VO_2$<br>Good on treadmill but lower on cycle than target |
| Zeni, Hoffman & Clifford (1996) | 8 men; 5 women<br><br>35 ± 4 yr<br><br>Healthy | x country skiing simulator<br>Rowing<br>Stair stepper<br>Treadmill<br>Cycle | 4 week habituation<br><br>3 stages on each machine of 5 mins at RPE 11, 13 & 15 | Treadmill superior for energy expenditure<br>All modes of exercise met $VO_2$ ACSM guidelines except cycle between RPE 13-15<br><br>All met %HR ACSM guidelines except airdyne at RPE 11 |
| Eston & Thompson (1997)<br><br>Clinical | 42 males & females<br><br>Under 70<br><br>Some beta-blocked | Cycle ergometer | 22 beta-blocked<br>20 control<br><br>2 x sub maximal test<br>Test 1 – estimation trial<br>Test 2 – Production trial @ RPE 9, 13, 15 & 17 | In both tests r = .96 + .99<br>Prediction of max power output lower in production mode<br><br>PO lower in women |

| | | | | |
|---|---|---|---|---|
| Kang, Chaloupka *et al.* (1998) | N=17 (10men & 7 women)<br><br>26 ± 4 yr<br><br>Sedentary? | Arm cranking + cycle | GXT as estimation trial<br>2 x production trials on arm and leg ergometer at RPE equivalent to 50 + 70% $VO_2$peak | No sig diff in HR at 50 or 70% or PO But they were lower in production<br><br>Valid in arms at 50 + 70%<br>Valid in legs only at 50% NOT 70% |
| Buckley, Eston & Sim (2000) | 10 (6 men & 6 women)<br><br>27.3 ± 11.7yrs<br>Blind | Cycle | GXT then3 x trials in production mode at RPE 9, 11 & 13 (random order) | No sig diff in %HRmax or %$VO_2$max between trials<br><br>Improved with practice |
| Katsanos, Cheuvront, Haymes (2001) | 11 males<br>26.6 ± 1.3yrs<br><br>52.6 ± 1.6 ml/kg/min<br><br>Healthy | Cycling & Treadmill walking | GXT then<br>Cycling and walking at RPE 11, 13 & 15 | Cycling has higher energy expenditure than walking at RPE 11<br>No sig diff at RPE 13<br>Walking higher energy expenditure than cycle at RPE 15<br><br>Worked at correct intensity to meet ACSM guidelines |
| Hartshorn & Lamb (2004) | N =18 (9 males & 9 females)<br>27.6 ± 5.4 yr<br><br>Healthy active | Cycle | 4 x trials each at RPE 9, 13, 15 + 17<br><br>Investigating reliability | Poor reliability using LoA, ICC or CV<br><br>ICC = (0.8 – 0.89) unacceptable + moderate |
| Kang, Chaloupka *et al.* (2009) | N = 20 (10males + 10 females)<br><br>22.4 ± 3.7yr<br><br>32.2 ± 5.0 ml/kg/min | Cycle ergometer | GXT to determine RPE at 50 + 75% $VO_2$peak<br><br>4x trials<br>50% for 20 + 40mins<br><br>75% for 20 + 40mins | Slight under production during production trial in HR + PO<br><br>No sig diff in $VO_2$ between estimated and production<br><br>No diff in RPE over duration (20 + 40min bouts) |

Note: est = estimation trial; prod = production trial

Eston, 1997; Buckley *et al.* 2000). However, Hartshorn and Lamb (2004) later questioned this assertion in their study of 18 healthy men and women who completed four sub-maximal perceptually-regulated exercise trials involving four bouts at RPE levels 13, 15, 9 and 17 (in that order). This study was noteworthy for its use of a more appropriate statistical analysis technique, the 95% limits of agreement (LoA), than used in previous studies of adults (other than Buckley *et al.,* 2000) to assess the reproducibility of the physiological responses across repeated trials. Typically, studies have used the Pearson correlation, which is a measure of *relative* agreement rather than *absolute* agreement (Nevill & Atkinson, 1997; Lamb, 1998). Contrary to the earlier studies, Hartshorn and Lamb observed no discernible improvement in the reliability of responses across the four trials, and considerable variation occurred between trials, for example, PO at RPE 15 differed by up to 70 W (trial 2-3), equating to nearly 40%. Also at RPE 9 between trials 2 and 3, the within-subject variation was 58.3%. The variance was equally large for percentage maximal HRR (65% at RPE 13, trial 1–2) and $\dot{V}O_2$ (36.5% at RPE 17, trial 3–4). Wide-ranging intraclass correlations (0.01 to 0.90) for power output across the four RPE levels reinforced the level of disagreement that was observed and led the researchers to question the use of perceived exertion to regulate exercise. It is not clear why these differences occurred, as Buckley *et al.* (2000) utilised a similar protocol and with the same statistical procedures provided data to support the reliability of RPE in production mode (although they used a RPE scale in Braille). What may be relevant is that Hartshorn and Lamb (2004) did not provide a prior maximal GXT as other studies have done (Eston & Williams, 1998; Dunbar *et al.,*

1992; Dunbar *et al.,* 1994; Kang *et al.,* 1998; Buckley *et al.,* 2000; Katsanos *et al.,* 2001; Kang *et al.,* 2009) and denied their participants exposure to the full perceptual range. In fact, such a design is actually more reflective of what would happen in the 'real world'. From an empirical perspective, this approach should be considered in future studies as it will not 'contaminate' exercisers' introduction to using RPE in production mode. Instead, the estimation GXT (if needed) could follow the production trials.

### 2.1.8 Upper-body exercise (arm ergometry and wheelchair users)

Very few studies have investigated the regulation of exercise intensity during upper-body exercise (Table 2.4, p. 38). The first one (Ward *et al.,* 1995), arguably the most externally valid, required 17 wheelchair users (aged 11-30 years) to regulate their exercise intensity at RPE 7, 10, 13 and 16 for 400 m around an oval track (either a 200 m indoor or 400 m outdoor) following a session incorporating a maximal GXT on an arm ergometer and a familiarisation session with the Borg RPE scale. The production protocol was repeated one month later to assess the consistency of the participants' responses. From the analysis it was evident that everyone could distinguish successfully between the different RPE levels as linear increases in HR were observed. However, the regression lines of RPE and HR showed a tendency for the wheeling intensities to be over-produced (especially at low RPEs) compared to the estimation trial. Alongside this, HR responses for a given RPE were consistently higher in the production trials than the estimation, which is quite the opposite to 10–15% lower values observed in cycle ergometry (Chow & Wilmore, 1984; Dunbar *et al.,* 1992; Glass *et al.,* 1992;

Kang *et al.,* 1998, 2003). A possible explanation for this was that while the estimation trial was conducted on an arm ergometer at a set cadence (50 revs·min$^{-1}$), the production trials took place in participants' own wheelchairs at self-selected speeds, which subsequently were seen to be higher than those expected from their estimation trial. There was however, no difference in the responses across the two production trials, suggesting a high retention of the ability to regulate over one month. It was also noted that the consistency was better at the higher intensities (RPE 13 and 16), as noted with other (non-wheelchair) studies (Bayles *et al.,* 1990; Eston *et al.,* 1987; Smutok *et al.,* 1980). Incorporating an adjustment to negate the above over-production of effort, Ward *et al.* (1995) offered an application of their findings in the form of recommended RPE regulation (prescription) levels that 'matched' the HR generated during an arm ergometer estimation trial. That is:

(i) To achieve HR equivalent to RPE 10, prescribe RPE 6-7

(ii) To achieve HR equivalent to RPE 13, prescribe RPE 9-10

(iii) To achieve HR equivalent to RPE 16, prescribe RPE 14-15

The above suggestions are similar to those by Ceci and Hassmen (1991) who advocated a reduction of two RPE levels when prescribing exercise for field running from treadmill exercise among adults and children. However, given that Ward *et al.* (1995) do state that their younger participants had more difficulty at the lower prescription levels (no data provided), it would have been advisable to separate their data from those of the adults and reconsider their suggestions. Indeed, they did split the sample for training status and noticed that the sedentary

group produced a narrower range of wheeling speeds (0.2-0.3 $m \cdot s^{-1}$) than the active subjects (0.6-0.7 $m \cdot s^{-1}$).

In the first study among able-bodied participants, Kang *et al.* (1998) found RPE to be a valid means of regulating exercise intensity during arm ergometry at 50 and 70% $VO_2$peak. Having employed an arm ergometer at 50 $revs \cdot min^{-1}$ for the initial maximal GXT (to gain target RPEs for 50 and 70 % $\dot{V}O_2$peak), the same mode of exercise was also used (at the same cadence) for the subsequent production trials at the RPE values obtained from the GXT at 50 and 70% $\dot{V}O_2$peak. On the basis that no significant differences in $\dot{V}O_2$, PO, and HR were observed at either 50 or 70% $\dot{V}O_2$peak between the estimation and production trials, the utility of RPE for regulating exercise in arm ergometry was affirmed. Interestingly, the same study also examined the same relationships during cycle ergometry but was able only to confirm the validity of perceptually-regulated exercise at the lower of the two target intensities (50% $\dot{V}O_2$peak). This could possibly be more to do with the smaller muscle mass used in arm ergometry and a corresponding high level of local of muscle fatigue and sensitivity feeding into the perception of effort than an invalid ability during cycling. Most recently, similar findings have been observed in spinal cord injured patients while regulating their exercise for 20 minutes on a hand cycle at 50 and 70% $\dot{V}O_2$peak (Goosey-Tolfrey *et al.,* 2010). This study is discussed in more detail in the 'special populations' section (p. 44).

**Table 2.4** Summary of arm ergometry studies in RPE production mode.

| Study | Participants | Exercise mode | Protocol | Key Findings/Interpretations |
|---|---|---|---|---|
| Ward, Bar-Or, Longmuir & Smith (1995) | n = 17<br>11- 30 yr | Arm ergometry + Wheelchair | GXT on arm ergometer then regulating at RPE 7, 10, 13 + 16 for 400m in a wheelchair and repeated one month later | Supports use of RPE to regulate exercise intensity but better at higher intensities. |
| Kang, Chaloupka *et al.* (1998) | n=17 (10men & 7 women)<br><br>26 ± 4 yr<br>Sedentary? | Arm cranking + cycle | GXT as estimation trial<br><br>2 x production trials on arm and leg ergometer at RPE equivalent to 50 + 70% $VO_2$peak | No sig diff in HR at 50 or 70% or PO, but they were lower in production<br>Valid in arms at 50 + 70%<br>Valid in legs only at 50% NOT 70% |
| Goosey-Tolfrey, Lenton *et al.* (2010) | 8 male<br>36.4 ± 6.8 yr<br><br>Spinal cord injured<br>Well-conditioned | Arm ergometer | GXT to determine $VO_2$peak<br><br>2x visits PO @ 50 + 70% $VO_2$peak<br><br>RPE regulated x2 | No difference in $VO_2$, HR, PO and lactate between estimation and production although a slightly higher PO in production RPE than controlled session at 70% $VO_2$peak |

### 2.1.9 Rowing Ergometry

Only three studies (Table 2.5, p. 40) have investigated whether the Borg RPE scale is an appropriate method for regulating exercise intensity during rowing ergometry (Buckley *et al.,* 2000; Marriott & Lamb, 1996; Zeni *et al.,* 1996). In the study by Marriott and Lamb (1996) nine male competitive rowers completed a maximal incremental rowing test followed by a production trial at RPEs 15, 11, 17, 13 and 19 (in that order). High significant correlations ($p < 0.01$) for HR ($r = 0.82$) and PO ($r = 0.84$) were observed between the estimation and production trials implying that the participants could regulate the exercise intensity using RPE. However, closer inspection of the findings reveals that regulation was only successful at HRs equivalent to RPE 15 (170 beats·min$^{1}$) and above, which concurs with the initial research in this field conducted on a treadmill (Smutok *et al.,* 1980). It appears that the participants were quite poor at regulating exercise at RPE 13, with mean HR being 17 beats higher (+11.4%) in the production trial than in the estimation trial, although the authors explain that this might have been due to the order of presentation of the bouts, with RPE 13 following RPE 17 perhaps without adequate recovery time for the HR response. With respect to PO, the participants were only accurate at RPE 17, which produced the only non-significant difference between the trials. The mean production errors were 52 W at RPE 15 and 25 W at RPE 17, which are in line with those reported for cycling and treadmill (Dishman *et al.* ,1994).

**Table 2.5** Summary of rowing ergometry studies in RPE production Mode.

| Study | Participants | Exercise mode | Protocol | Key Findings |
|---|---|---|---|---|
| Marriott & Lamb (1996) | 9 males<br>28.6 ± 6.3 yr<br><br>Trained competitive rowers | Rowing | Estimation trial range of power output and HR<br><br>Then production trial @ 15, 11, 17, 13 & 19 | High correlation .95 HR + RPE<br>WO + RPE = .96<br>Production mode r= .82 + .84<br><br>No sig diff 15, 17, 19 but was at 11 + 13<br><br>WO sig diff except RPE 17 |
| Zeni, Hoffman & Clifford (1996) | 8 men; 5 women<br><br>35 ± 4yr<br><br>Healthy | x country skiing simulator<br>Rowing<br>Stair stepper<br>Treadmill cycle | 4 week habituation<br><br>3 stages on each machine of 5 min at RPE 11, 13 & 15 | Treadmill superior for energy expenditure<br><br>All modes of exercise met $VO_2$ ACSM guidelines except cycle between RPE 13-15<br><br>All met %HR ACSM guidelines except airdyne at RPE 11 |
| Buckley *et al.* (2000) | 19 healthy participants<br><br>19 – 30 yr | Treadmill & Rowing | 3 x treadmill & rowing trials in random order regulating at RPE 13 | Treadmill HR was higher than rowing by approx 20bpm<br><br>Practice improved repeatability. |

Research published by Zeni *et al.* (1996) at about the same time generally agrees with these findings, although they focused on the validity of regulation across the ranges of RPE 11–13. In doing so they demonstrated that regulating

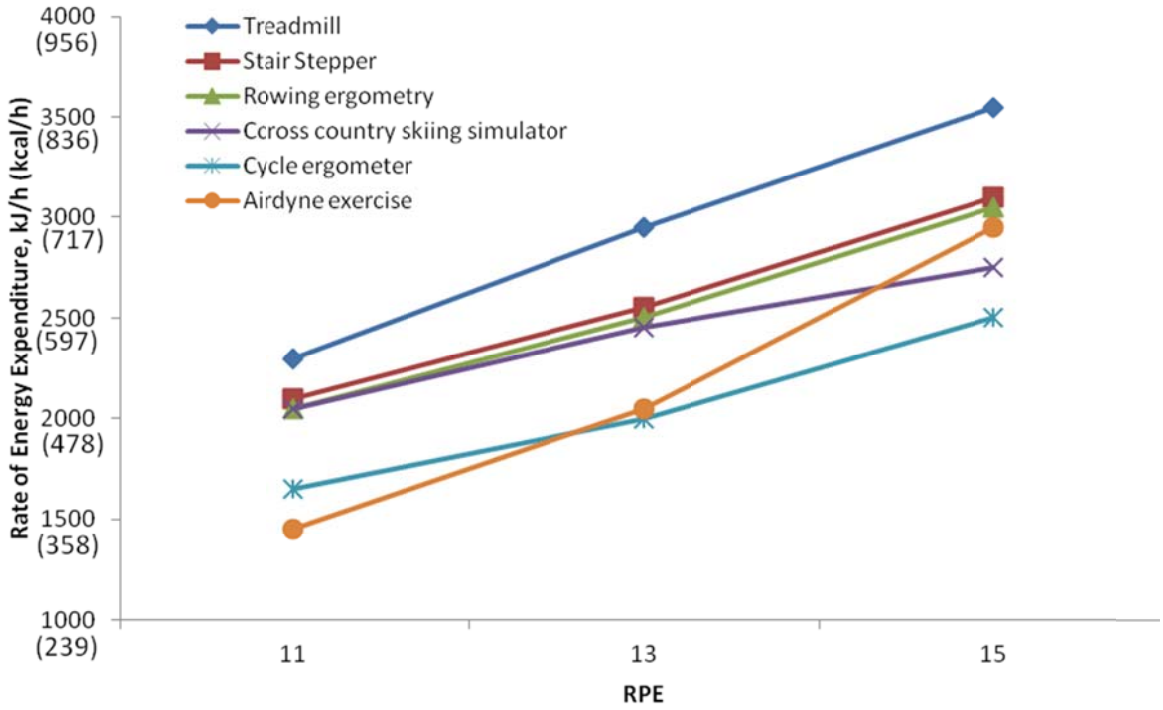


**Figure 2.3** Mean rates of energy expenditure as a function of RPE for six modes of exercise (re-drawn from Zeni *et al*., 1996)

exercise in this range placed participants within the recommended guidelines for enhancing fitness for %HRmax (RPE 11 = 69%; RPE 13 = 75%; RPE 15 = 80%) and for % $\dot{V}O_2$max (RPE 11 = 51%; RPE 13 = 59%; RPE 15 = 70%). Rowing was also seen to elicit higher rates of energy expenditure than both cycling and the Airdyne machine at all three RPE levels (Figure 2.3). The differences observed between the two studies may be explained by the fact that participants in the Zeni *et al.* (1996) study had eight practice sessions compared to the single estimation

trial for the participants in the Marriott & Lamb (1996) study. Furthermore, that the participants were described as 'competitive rowers' in the Marriott & Lamb paper might have meant they were not familiar with exercising at such a relatively low RPE as 13, a level which later on Buckley *et al.* (2000) demonstrated as benefitting from practice.

### 2.1.10 Cross-country skiing and stair stepping

Cross-country skiing and stair stepping were scrutinised along with other exercise modalities in one of the few studies of its kind by Zeni *et al.* (1996), as described above. Following the aforementioned eight practice sessions, the participants engaged in regulating exercise at RPE levels 11 (fairly light), 13 (somewhat hard) and 15 (hard) on each of the exercise machines and were seen to be exercising at 70%, 74% and 78% HRmax, respectively, on the cross-country machine, and at 68%, 76% and 83% HRmax, respectively on the stair stepper. Evidently they were exercising at an appropriate intensity (60–90% HRmax) for improvements in cardio-respiratory fitness (ACSM, 2010) across the three RPE levels. Notably, HR was significantly higher ($p < 0.05$) in both modes than the cycle ergometer and Airdyne, as was energy expenditure, whilst blood lactate concentrations for the cross-country skiing were the lowest out of all the exercise modes at RPE 13 and, conversely, were the highest for stair stepping. As noted previously, some of these inter-mode differences may be explained by the variability in RPE responses (by 2–3 units) that occurs when participants switch between exercise types (Ceci & Hassmen, 1991; Ward *et al.,* 1995). In the only other study on stair stepping Walker, Marriott and Lamb (1996) found among 15

young active females that their regulation of exercise intensity via RPE was valid, with participants, on average, able to produce three out of four intensities (at RPE 12, 15 and 18, but not 9) to within 6 beats·min$^{-1}$ (+4%) and 7 W (+7%) of target values. On a test re-test basis the performance was seen to be highly reliable, with intraclass correlations being 0.98 for both heart rate and power output.

### 2.1.11 Swimming

Green *et al.* (1999) conducted the only investigation regarding the regulation of exercise intensity via Borg's rating of perceived exertion scale during swimming. Nineteen regular male and female swimmers completed six trials utilising an estimation-production paradigm, comparing front crawl swimming to cycle and arm ergometry, and incorporating 'overall' and 'differential' (arms separately) RPE. Following a maximal test on a cycle to anchor 'overall' sensations for RPE 7 and 19, participants used an identical protocol to (verbally) estimate RPE overall each minute relative to their effort ratings anchored in trial one. A third trial involved swimming 150 meters front crawl at self-selected intensities equating to 'overall' (whole body) at RPE values of 12 and 16. This same procedure was then repeated for RPE 'arms' on an arm ergometer. Their analysis revealed that %HRmax at RPE 12 was significantly ($p < 0.05$) higher for swimming (78 ± 7%) than cycling (64 ± 10%) although not so at RPE 16. The arm ergometry intensities were not consistent with those for swimming, being significantly lower at both RPE 12 (58 ± 7% HRmax versus 84 ± 10%) and 16 (74 ± 6% HRmax versus 93 ± 10%).

It is quite clear from this study that exercise intensity regulation using RPE during front crawl swimming meant that participants worked at high intensities, especially at RPE 16, and should be viewed with caution for beginners or clinical populations. It may be that adjustments are needed, in the manner suggested by Ceci & Hassmen (1991) and Ward *et al.* (1995), when participants switch between exercise modes, although Green *et al.* (1999) do not allude to this. It is worthy of mention though, that no practice trials were performed for the swimming exercise, which is a limitation. Moreover, it can be questioned whether 150 m is enough distance to regulate the intensity appropriately and if further distances might yield different outcomes. Also, the only dependent variable in this study was HR and it would be interesting to see how other measures responded to perceptually-regulated swimming.

### 2.2 Special populations

As with healthy populations, the majority of research has focused on the application of RPE in its estimation mode, and has provided support for its use amongst people with cardiac conditions (Buckley, Sim & Eston, 2009; Connolly, Fernhall & McHugh, 1996; Pollock, Jackson & Foster, 1986; Squires Rod, Pollock & Foster, 1982), respiratory disorders (Ingemann-Hansen, Bundgaard & Halkjaer-Kristensen, 1980; McGavin, Gupta, & McHardy, 1976), neuromuscular diseases (Bar-Or & Reed, 1986), rheumatoid arthritis (Nordemar, Edstrom & Ekblom, 1976), diabetic autonomic neuropathy (Colberg, Swain & Vinik, 2003), and wheelchair users (Ward *et al.,* 1995). To the author's knowledge, only two special populations have been investigated with respect to Borg's 6-20 RPE scale being utilised in

production mode; cardiovascular disease patients (Eston & Thompson, 1997; Llarraza, Myers, Kottman, Rickli & Dunach, 2004) and spinal cord injured (Goosey-Tolfrey *et al.,* 2010).

### 2.2.1 Cardiovascular patients

Eston and Thompson's (1997) study involved similar samples of male and female patients prescribed either with medication (atenolol, 25-100 mg) or without (control group). Both groups completed a YMCA sub-maximal cycle GXT which provided RPE values in estimation mode and a prediction of maximum work rate, followed two days later by an incremental production trial at RPEs of 9, 11, 13, 15 and 17. The relative intensity produced at each RPE bout was calculated as a percentage of the predicted maximum work rate (%Wmax). Analysis overall revealed significant increases ($p < 0.01$) in %Wmax across successive RPE levels during the production trial, and no differences between the two groups at each level (Figure 2.4, below). However there was a sex by group interaction effect ($p < 0.01$), with the intensities produced at RPE 9 and 13 being higher for the women in the medication (treatment) group than those in the control group. From the limited data available, it appears that when the women (especially the treatment group) were requested to regulate their intensity in the production trial, they became more conservative and overestimated the exercise intensity, with the authors suggesting some degree of caution being required when transferring patients from estimation to production mode. Also, the relative intensity at RPE 13 produced a range of 39-48% of maximum, which is somewhat lower than reported previously in healthy populations (Eston & Williams, 1988), although just within the guidelines for

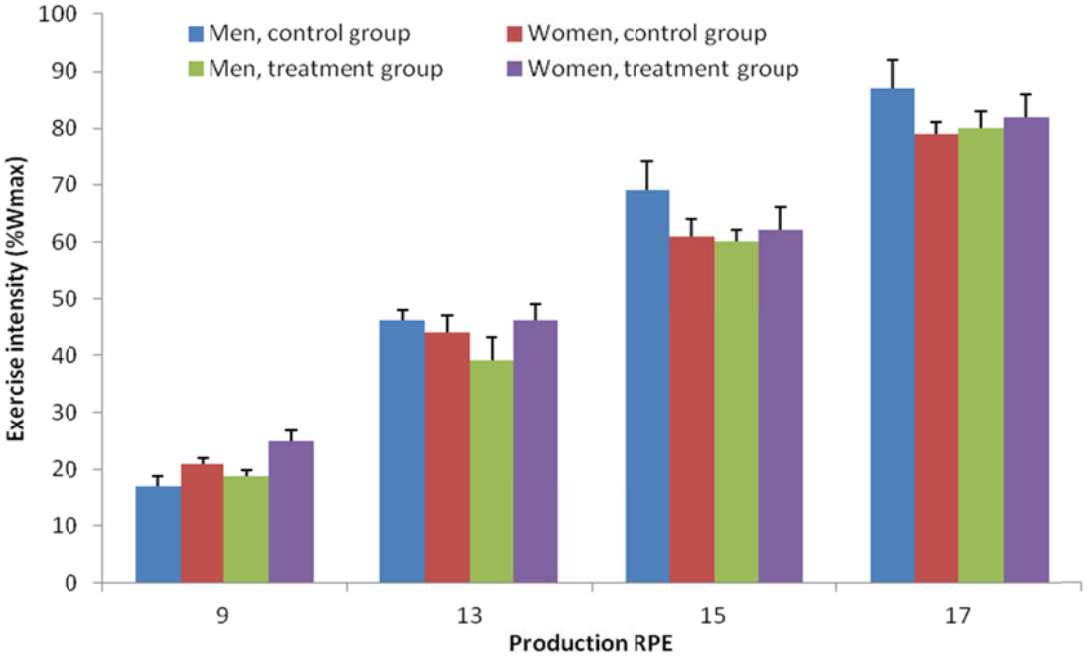


**Figure 2.4.** Comparison of relative exercise intensity (%Wmax) produced at RPE levels 9, 11, 13, 15 and 17 during the production protocol (redrawn from Eston & Thompson, 1997).

exercise prescription (ACSM, 2010). However, it must be noted that participants were not afforded a practice session, which has been shown to improve the accuracy of production trials (Buckley *et al.,* 2000, Eston *et al.,* 2005, 2006). Previous studies (Eston & Connolly, 1996; Derman, Sims & Noakes, 1992; Kelly, 1985), albeit focusing on RPE in estimation mode, have reported that the type of β-blocker used has different effects on RPE. Non-selective β-blockers are associated with reductions in $\dot{V}O_2$max, increased muscle fatigue and increased peripheral resistance, whereas with the cardio-selective β-blockers there is less local muscle fatigue. Eston and Thompson (1997) suggest this should be an important

consideration when using RPE to regulate exercise intensity. The authors concluded that their findings provide some support for the efficacy of RPE in regulating exercise intensity in some cardiac rehabilitation settings, although the lack of a maximal criterion measure of exercise capacity and/or oxygen uptake values must limit any claims for its validity.

An interesting study involving stable (low risk) cardiac rehabilitation patients assessed the training responses to one month of self-regulated exercise at an intensity they perceived as 'somewhat hard' (Llarraza, *et al.* 2004). Seventy eight patients were randomly allocated into one of three groups: group 1 trained at 70% of heart rate reserve (HRR) on a cycle ergometer that automatically adjusted to maintain the target intensity; group 2 performed indoor and outdoor exercises at RPE 12-14 (with no feedback from heart rate or work rate); group 3 used a combination of HRR and perceived exertion. The mean training heart rates of the groups were similar (group 1 = 107 ± 10 beats·min$^{1}$, group 2 = 105 ± 10 beats·min$^{1}$ and group 3 = 106 ± 8 beats·min$^{1}$) and all significantly increased their exercise capacity (group 1, +31%, group 2, +23% and group 3, +31%; $p < .01$) over the training programme. Importantly, those patients who perceptually-regulated their exercise achieved the same training benefits as those whose training was prescribed using a sophisticated heart rate feedback cycle ergometer. The authors of the study concluded that these results indicated that close heart rate monitoring may not be required for many stable cardiovascular disease patients to accomplish improvements from a rehabilitation programme.

### 2.2.2 Spinal cord injured

Similar findings to those observed in healthy participants during arm ergometry (Kang *et al.,* 1998) have also been observed in spinal cord injured patients (T11 incomplete to T4 complete) while regulating their exercise for 20 minutes on a hand cycle at 50 and 70% $\dot{V}O_2$peak (Goosey-Tolfrey *et al.,* 2010). In this study, parity was observed between the HR, PO, $VO_2$ and blood lactate responses recoded in two experimenter-prescribed bouts (50 and 70% $\dot{V}O_2$peak, calculated from a prior GXT) and those produced in two RPE-regulated sessions (based on the RPEs that was reported in the GXT). Accordingly, the limited research to date seems to support the validity of perceptually-regulated exercise in this specific population.

## 2.3 Methodological issues

Following the review of the studies employing intensity regulation via RPE, several areas of concern have arisen, including that the instructions provided appear to be for using RPE in estimation mode only; the possibility of prior maximal GXT tests inadvertently affecting the 'anchoring' process; insufficient practice sessions being afforded to participants; the inappropriate use of correlation techniques to appraise validity and reliability.

### 2.3.1 Instructions and administration of the scale

The appropriate administration of the RPE scale is of paramount importance for enabling valid and reliable data, whether used in estimation or production

mode. Common errors in administration and presentation have been reported, including alterations to the appearance, incorrect positioning of the verbal anchors, changes to the adjectives and adverbs, introducing colours with different emotional meaning, and shortening or changing the instructions (Borg, 1998, p. 15). Arguably, any of these changes to the original scale will alter its metric properties, consequently affecting the readings recorded during estimation procedures or the intensities produced during regulation trials. In addition, there are other sources of potential unintended variance, such as a lack of clarification that the participant/exerciser is required to provide an overall integrated rating which incorporates both peripheral muscular and central cardio-respiratory sensations, and that there is no right and wrong answer. Also, the participant must understand that any rating they provide (or use to regulate) represents how hard the effort feels at that moment. Moreover, the scale has to be accessible (mounted within finger reach or presented in a large format) at all times during testing (Buckley *et al.,* 2000).

Due to the limited information that can be presented in journal articles it could be presumed that researchers use the validated scale in its original format, along with appropriate instructions, as presented by Borg (1998, p. 105). Sometimes the authors state this, but often they do not. In the particular case of the RPE scale being used in production mode, however, it appears that, almost without exception, researchers have provided the same instructions as for its use in estimation mode. This is surprising given that the two applications of RPE require different things of exercisers and, undoubtedly, such an oversight presents

another confounding influence on the application of perceived exertion. Until very recently, no production-specific instructions have existed.

Another point researchers and practitioners should be aware of is that it is estimated that 5% to 10% of participants (Borg, 1998, p.15) may have difficulties in understanding the concept of RPE and the instructions and requests to respond in the way that Borg had hoped. Although no data exist to quantify this, the percentage may actually be even higher if all individuals are considered, including those whose experiences of physical exertion are very limited and/or span a narrow range, and those who have difficulty interpreting the numbers and semantics of the RPE scale. If researchers or practitioners are faced with these complications, then additional explanations may be necessary to aid participants in their understanding of how to use the scale.

### 2.3.2 Anchoring and order of testing

As mentioned above, the RPE scale should only be applied following a set of standardised instructions (Borg, 1998) which incorporate a process termed 'anchoring'. Anchoring represents an attempt by the practitioner/researcher to help the exerciser link their full exercise stimulus range with the full RPE response range; the assumption being that when this link is made the basic assumptions of Borg's range model are satisfied (Gearhart, 2008). That is, participants' previous sensations of exertion are anchored to the top ('extremely hard/maximal exertion') and bottom ('no exertion at all') ratings on the RPE scale. There are primarily three methods designed to facilitate this process; 'memory', 'exercise' and a combination

of 'memory and exercise' (Robertson, 2004). *Memory* anchoring requires an explanation of the feelings related to the low and high perceptual descriptors and recollection of previous experienced feelings during exercise, with no exercise test being performed. Alternatively, *exercise* anchoring involves the anchors being experienced rather than defined and requires the exerciser to perform an exercise test. The following protocol is suggested by Noble and Robertson (1996, p. 79) to allow experimental subjects or clients to feel the two extreme anchors of the scale during an exercise test. Here, the anchor numbers are assigned to the sensations experienced whilst exercising at a very low level (RPE 7) and at a maximal level (RPE 19). Prior to performing the test, it is explained that a rating of 6 should be assigned to any feelings of exertion that are less than those experienced whilst exercising at the 'extremely light' (RPE 7) intensity and a rating of 20 should be assigned to any feelings of exertion that are greater than those experienced during the extremely high (hard) exercise intensity. Anchoring of this type is not always feasible, especially in gym-based settings or with sedentary or clinical populations and is usually conducted in a laboratory setting. The combined procedure usually involves the participant undertaking the maximal test, followed by the memory anchoring. Interestingly, Gearhart (2008), albeit in using RPE in estimation mode, demonstrated that there was no difference ($p > 0.05$) in % $\dot{V}O_2$peak across a broad range of interpolated RPE levels (7 to 19) between a group that had undertaken 'memory' anchoring only and a group that had received 'exercise and memory' anchoring (Table 2.6, below), demonstrating that a maximal GXT may not be

necessary. It would be interesting to see if this was replicated for the responses elicited during production trials.

The majority of studies utilising perceived exertion to regulate exercise intensity have used an estimation-production paradigm whereby participants have performed a maximal GXT first. A likely effect of this is that the GXT might 'contaminate' the anchoring process as maximal testing would not usually be afforded to participants outside of the laboratory or in sedentary or clinical populations due to issues of safety and not reflect a real life scenario. Future research should consider performing any maximal testing (if needed) following production trials, until data is available to verify it is not affecting and artificially enhancing results.

**Table 2.6** Percent $\dot{V}O_2$peak at each rating of perceived exertion (RPE) for the memory group and the combined exercise and memory group (Gearhart, 2008)

| RPE | Memory (*n* = 18) | Combined exercise and memory (*n* = 18) |
|---|---|---|
| **7** | 32.6 ± 8.0 | 34.5 ± 8.1 |
| **9** | 43.8 ± 7.6 | 46.9 ± 6.7 |
| **11** | 60.0 ± 7.0 | 57.3 ± 6.3 |
| **13** | 67.1 ± 5.9 | 69.2 ± 5.7 |
| **15** | 80.2 ± 5.2 | 77.6 ± 5.4 |
| **17** | 90.8 ± 4.4 | 91.5 ± 5.0 |
| **19** | 97.8 ± 3.4 | 97.9 ± 2.9 |

Results expressed as (mean ± SD)
*Note:* there were no significant differences between groups for any variable.

In the few studies that have not performed maximal testing or estimation trials prior to effort production trials, there have been conflicting results with some showing support (Buckley et al., 2000; Zeni *et al.*, 1996; Eston *et al*., 2012) and others questioning its appropriateness (Hartshorn & Lamb, 2004).

### 2.3.3 Practice session/s and familiarisation

Linked to the above description of 'exercise' anchoring is the effect of familiarisation or practice on the reproducibility (reliability) of perceptually-regulated exercise, which has been the focus of several investigations (Eston & Williams, 1988; Kang *et al.,* 1998; Lamb Eston, & Corns, 1999; Buckley *et al.,* 2000; Eston *et al.,* 2005; 2006; 2008; also Studies 1–3 of this thesis). The general consensus in the literature is that practice (exposure to more than two trials) enhances the reliability of perceptual regulation, and thereby its validity, and indeed is necessary when participants are regulating exercise via the RPE scale during treadmill (Smutok *et al.,* 1980; Ceci & Hassmen, 1991), cycling (Eston & Williams, 1988; Buckley *et al.,* 2000) and rowing (Buckley *et al.,* 2000). More often it is at the lower levels of the RPE scale (9-13) that improvements in effort regulation occur (Smutok *et al.,* 1980; Ceci & Hassmen, 1991; Eston & Williams, 1988), since during the initial trial these intensities provide less sensory feedback into an individual's perceived exertion.

However, some of these studies have used what should be considered inappropriate statistical techniques to assess the reliability of perceptually-regulated exercise, in particular tests of mean difference (Smutok *et al.,* 1980;

Eston & Williams, 1988) or correlation coefficients (Buckley *et al.,* 2000; Ceci & Hassmen, 1991), instead of the more suitable limits of agreement (Buckley, 2012; Lamb, 1998). The implication of this is a potential mis-interpretation of the effects of practice and subsequent claims that target exercise intensities can be produced consistently thereafter. Nonetheless, the few studies that have used the limits of agreement (LoA) technique have, in general, demonstrated narrower (better) agreement of responses following repeated trials (Buckley *et al.,* 2000; Eston *et al.,* 2005; 2006; also Studies 1–3 of this thesis). Contrary to this was the study by Hartshorn and Lamb (1998), who provided four identical cycle ergometry trials and observed no improvement in the consistency of the objective markers of exercise ( $\dot{V}O_2$, heart rate and power output) produced across a range of intensities (RPE 9, 13, 15 and 17), with relatively wide disagreement throughout. Notably, this was one of the few studies in which participants did not complete a maximal GXT prior to the perceptually-regulated trials and were therefore not provided with 'exercise' anchoring across the full perceptual range. Indeed, this scenario is actually more reflective of what would happen in 'real-life' exercise settings (beyond the laboratory or clinical environment) where maximal testing is usually not conducted.

Just how many practice trials are needed to optimise a person's use of the RPE scale in production mode is not clear. Research has typically only applied two to four repeat trials, although Zeni *et al.* (1996) afforded their participants eight familiarisation sessions and reported that good validity was displayed across a range of exercise machines and RPE levels. However, data were not presented

that revealed how many sessions were needed before stable responses were achieved. Clearly, this is a matter that warrants future research.

### 2.3.4 Statistical procedures

As alluded to above, a common feature of the research conducted to assess the reliability and validity of the RPE scale is the inappropriateness of the statistical procedures used. A point that has been argued in general for exercise science over the past two decades (Buckley, 2012; Lamb, 1998; Nevill & Atkinson, 1997; Atkinson, 1995) is the unsuitability of the bivariate correlation and tests of bias to quantify measurement reliability and validity. As the Borg 6-20 RPE scale is classified as an equidistant interval level tool (Eston & Reilly, 2008, p. 243), parametric statistical analyses have always been conducted with it, usually in the form of analysis of variance or a Pearson correlation. However, following the publication of Bland and Altman's seminal paper in 1986, exercise scientists began to recognise that correlation coefficients do not assess the level of agreement between two scores; they only appraise the association. So, if there are systematic changes between trial one and two (i.e. a particular participant achieves the highest score in trial one and two, and another, the second highest score in trial one and two, and so on) then the correlation coefficient will be high, suggesting good reliability. Similarly, a non-significant bias between trial means could reflect that half the participants scored higher on trial one than trial two, and the other half vice versa. Neither of these statistical approaches addresses the extent to which the trial-to-trial scores of the individuals in the sample agree. Instead, the 95%

limits of agreement (LoA) technique has been promoted as a more appropriate form of statistical analysis.

Unlike the correlation coefficient, LoA analysis allows reliability to be expressed in the unit of the measurement and quantifies the amount of agreement between repeated measurements of the same variable (and not the relationship). LoA analysis yields a statement on how close the repeated measures are for most participants (95%) in a sample. In a situation where there are identical test-retest scores and therefore perfect agreement between all the scores, LoA would give an average difference of zero units (and a standard deviation of zero). As this very rarely happens with human attributes, Bland and Altman (1986) recommended that the data (differences) of 95% of a sample should be considered as a point of reference, allowing for extreme measurements or outliers to be ignored in the appraisal of reliability (Lamb, 1998). Accordingly, the LoA take the form of the mean difference (bias) ± 1.96 multiplied by the standard deviation of the differences (SDdiff). The 1.96 x SDdiff reflects the amount of within-subjects variation (trial-to-trial), or so-called *random error,* for 95% of the sample's differences. Thereafter, the experimenter/researcher has to make a judgement about how large or meaningful such variation is. This presumes, however, that the researcher is very familiar with the variable being assessed and is therefore able to make an informed decision, which does not rely upon the outcome of a hypothesis test (of significance). Ideally, such a decision is predicated on the basis of *a priori* 'analytical goals' (Atkinson & Nevill, 1998). Moreover, the utilisation of this technique necessitates a strict analysis of the data whose interpretation is aided by

adopting a "worst case scenario" approach (Nevill & Atkinson, 1997) in which the extent of the variation between trials can be expressed by using an exemplar value. That is, "Given the calculated LoA, a person producing a HR of *x* beats·min$^{-1}$ in trial 1 could be expected to produce a HR of as high as *y* beats·min$^{-1}$ or as low as *z* beats·min$^{-1}$ in trial 2." In the two published studies that have used the LoA technique on RPE production data, one has supported an improvement in reliability following repeated trials (Buckley *et al.,* 2000) whereas the other has not, and indeed has questioned the reliability of RPE used in this mode (Hartshorn & Lamb, 2004). There is undoubtedly scope for more research on this theme.

## 2.4 Prediction of maximal exercise capacity from perceptually-regulated exercise.

Maximal exercise capacity, when expressed in metabolic equivalents, has been shown to be the single best predictor of all-cause mortality among men with or without cardiovascular disease (Myers, Prakash, Froelicher, Partington & Atwood, 2002), and when expressed as peak or maximal oxygen uptake ($\dot{V}O_2$max), a strong and independent predictor of mortality in patients with known cardiovascular disease (Aijaz *et al.* 2009; Kavanagh *et al.* 2002; Laukkanen *et al.* 2004). $\dot{V}O_2$max is generally regarded as the criterion measure of cardiorespiratory fitness and is commonly used to assess the effectiveness of an exercise intervention and to prescribe exercise training accurately (ACSM, 2010). However, the measurement of $\dot{V}O_2$max is expensive, requires specialist personnel, and a maximal effort on the behalf of the participant which raises health and safety issues

in untrained, elderly and clinical populations. Historically, these constraints led to the development of sub-maximal tests (cycling, stepping, or distance runs) which exploit the linear relationship between oxygen uptake and heart rate in order to predict $\dot{V}O_2$max. However, it is well known that when maximal HR (HRmax) is unknown, the error associated with the popular method used to predict it (220 minus age), can be as much as 20 beats·min$^{-1}$ (Londeree & Moeschberger, 1984; Buckley *et al.,* 2004). Coupled with the fact that HR rate can also be affected by medications (β-blockers) and environmental conditions (heat), the accuracy of its relationship with $\dot{V}O_2$ and the subsequent prediction of $VO_2$max is highly suspect (Buckley *et al.,* 2004).

The notion of utilising RPE to predict $\dot{V}O_2$max has recently re-surfaced as a viable alternative to HR since it is not susceptible to the above limitations. That is, a RPE of 19 or 20 reflects a person's theoretical maximum effort, regardless of age, and it is a measure that is not affected by medical conditions, such as atrial fibrillation, chronotropic and inotropic medications, or hot environments (Kang *et al.,* 1998; Eston & Connolly, 1996). It is with this in mind that two early studies explored the accuracy of RPE in *estimation* mode for predicting maximal work capacity (Morgan & Borg, 1976; Ljunggren & Johansson, 1988). These studies reported less error compared to heart rate; RPE predicted maximal work capacity was within 1%, whereas HR overestimated it by ~15% (Morgan & Borg, 1976). These findings were confirmed by Buckley *et al.* (1998) who observed among a mixed sample of sedentary, recreational and highly-trained men and women (*n* =

21, 18-43 years) that a regression equation based on RPEs reported during a sub-maximal cycle test predicted GXT-attained $\dot{V}O_2$max more accurately than the nomogram derived from the classic Astrand-Rhyming test. Although the nomogram method was seen to provide high correlations between predicted and measured scores ($r$ = 0.91), it underestimated criterion $\dot{V}O_2$max by -0.308 ± 0.407 L·min$^{-1}$. The regression equation ($\dot{V}O_2$max = 1.076 (RPE) + 0.085)) yielded better estimates of $\dot{V}O_2$max that were deemed to be acceptable. Recently, a study by Faulkner, Lambrick, Parfitt, Rowlands and Eston (2009) reported that the estimations of the fractions of $\dot{V}O_2$max elicited at each successive RPE were approximately 10% too high and that a correction factor was necessary to compensate for this (although this was not provided by the authors).

In the manner of Buckley *et al.* (1998), Okura and Tanaka (2001) attempted to predict $\dot{V}O_2$max from RPE using a multiple regression model incorporating work rate and RPE recorded during a sub-maximal graded cycling test. One hundred and 54 men (aged 34-64 years) were randomly allocated into a validation group ($n$ =100) and a cross validation group ($n$ = 54) and both performed a $\dot{V}O_2$max test and a sub-maximal graded cycling test up to a rating of RPE 15. The multiple regression analysis yielded an R value of 0.85 and a standard error of estimate of 261 ml·min$^{-1}$ and encouraged the authors to claim that the RPE method provided a valid estimate of $\dot{V}O_2$max. However, the sample-based regression is not appropriate for predicting individual $\dot{V}O_2$max values accurately. More recent studies have focused on individual-based predictions of $VO_2$max from RPE (in

estimation mode) in healthy populations (Faulkner & Eston, 2007; Faulkner *et al.,* 2009) and obese women (Coquart *et al.,* 2009; Coquart *et al.,* 2010) during cycle ergometry and multi-stage shuttle running (Davies, Rowlands & Eston, 2008) and all concluded that RPE values estimated during a sub-maximal GXT provided acceptable (non-significant) estimates of maximal oxygen uptake. What must be noted is that knowledge of the participants' health status and activity levels is required by the investigator to set the appropriate protocol. An alternative method is for the exerciser to regulate the exercise intensity him/herself; a line of investigation that has recently received considerable attention.

The potential for predicting $\dot{V}O_2max$ from physiological responses to sub-maximal perceptually-regulated exercise (RPE in production mode) was initially explored by Eston *et al.* (2005), though it wasn't the first study to assess whether self-paced exercise was predictive of oxygen uptake. Bassey, Fentem, Macdonald & Scriven (1976) simply explored whether self-paced walking on a level course of 256 m could be used to predict oxygen uptake among young men and the elderly. Walking pace, frequency and stride length, along with heart rate were measured in 24 elderly men and 10 young men and correlated with oxygen uptake values recorded from a cycle ergometer test. Although the correlations were modest (no data were provided) and no measure of perceived exertion was used, the study did provide support for the efficacy of self-paced activity. Indeed, a later modification of this approach involving self-paced stepping at intensities described to participants as, 'slow', 'normal' and 'fast' was conducted by Petrella, Koval, Cunningham &

Paterson (2001). High correlations were observed between treadmill assessed $\dot{V}O_2$max and that predicted from the self-paced stepping at 'normal' (females *r* =.93; males *r* = .91) and 'fast' (females *r* = .95; males *r* = .90) stepping paces, along with no difference observed in the prediction of $\dot{V}O_2$max between stepping performed in a laboratory and in a clinic setting.

The first study utilising Borg's 6–20 scale and RPE as the independent variable to predict maximum work capacity was conducted by Eston and Thompson (1997). It was hypothesised that the strong correlations between RPE, power output and $\dot{V}O_2$ would enable maximum work capacity to be predicted accurately. Patients with risk factors for cardiovascular disease (10 men and 10 women) first completed a sub-maximal estimation trial in which RPE was recorded during the incremental YMCA cycle test, followed by a production trial two days later in which they regulated the exercise to match levels 9, 13, 15 and 17 on the Borg scale. By extrapolating individual plots of work rate against RPE up to RPE 20, maximum work rates were predicted from the production trial and compared with those predicted from both the RPE estimation and YMCA trials. Analysis revealed no mean difference in estimated maximum work rate across the three protocols for the sample as a whole (see Figure 2.5, no actual data were provided only figures), though there was a significant sex by protocol interaction effect reflecting that the prediction of maximal work rate in the women's group from the effort production trial was lower ($p < 0.05$) than the RPE estimation or YMCA estimation trials (this difference was not observed in the men).

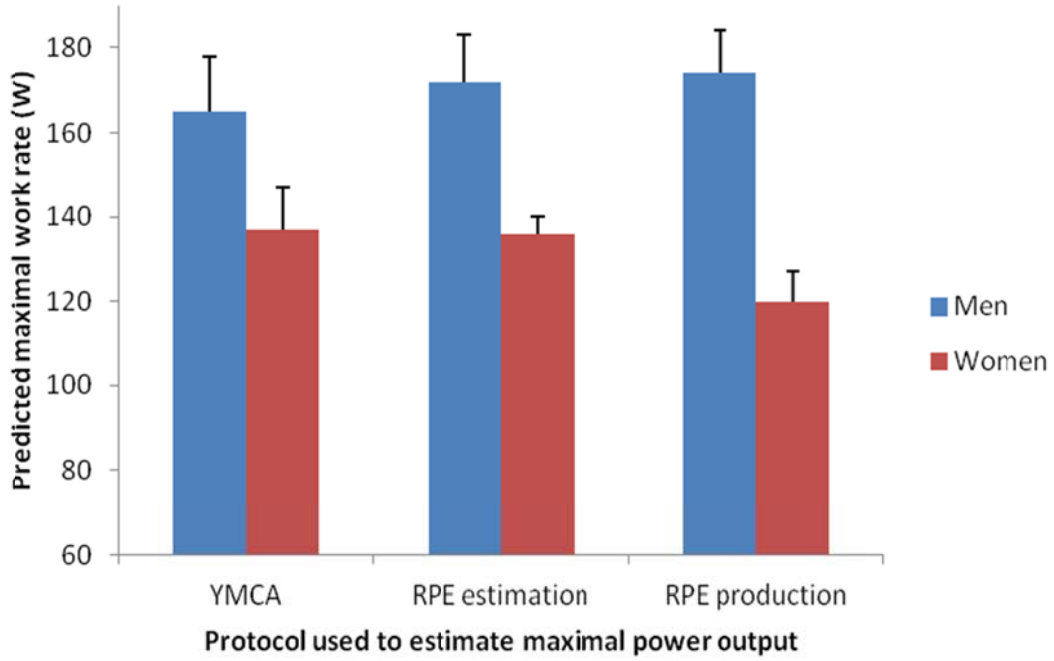


**Figure 2.5** Comparison of maximal power output predicted from the YMCA submaximal graded exercise test and from the rating of perceived exertion (RPE) estimation and production protocols when RPE = 20. Values are means ± SEM. (re-drawn and adapted from Eston & Thompson, 1997).

This indicated that they underestimated the level of resistance necessary for each RPE level in the production trial, yielding the lower prediction of maximal work rate. It was suggested that this may be due to the lack of exercise experience in this group, who were sedentary and not used to exercising regularly in activities of daily living and were not taking part in extra exercise (Eston & Thompson, 1997). Noteworthy is the fact that although a brief familiarisation session was afforded to the participants, subsequent research has shown that several trials are necessary to improve regulation when utilising RPE in production mode (Buckley *et al.,* 2000;

Eston *et al.,* 2005; 2006). A further limitation of this study is that there was no criterion measure of maximum work rate, thereby the prediction from the production protocol was only compared to that from other another predictive tests, which has its own inherent error.

The approach of predicting maximum exercise capacity from data collected in a perceptually-regulated trial was re-visited by Eston *et al.* (2005) who sought to predict $\dot{V}O_2$max from the sub-maximal $\dot{V}O_2$ values produced at five RPE levels (9, 11, 13, 15 and 17, presented in that order). Ten active males performed a GXT to exhaustion to provide a criterion $\dot{V}O_2$max, followed by three identical sub-maximal RPE production protocols on a cycle ergometer. In the manner of Eston and Thompson (1997), linear regression analysis was performed on the $\dot{V}O_2$ values at each RPE and extrapolations were made to RPE 20 to provide a corresponding $\dot{V}O_2$max prediction. Analysis revealed a non-significant ($p > .05$) difference between the measured $\dot{V}O_2$max values (48.8 $ml \cdot Kg^{-1} \cdot min^{-1}$) and those predicted from the three production trials (47.3, 48.6 and 49.9 $ml \cdot Kg^{-1} \cdot min^{-1}$), and LoA of 1.5 ± 7.3, 0.2 ± 4.9 and 1.2 ± 5.8 $ml \cdot Kg^{-1} \cdot min^{-1}$ between the participants' actual $\dot{V}O_2$max and the predicted values from each of the three trials, respectively. The authors concluded that these LoA, particularly for the second and third trials, were within acceptable limits of tolerance and reflected a degree of accuracy that was as good, if not superior, to what could be expected from existing sub-maximal prediction protocols such as those reported by Buckley *et al.* (2004) for the Chester Step Test of -2.8 ± 6.1 $ml \cdot Kg^{-1} \cdot min^{-1}$. However, it is difficult to compare to other established sub-

maximal predictive methods due to the reliance upon the size of the bivariate correlations or percent mean difference, rather than the range of the within-subject variation (Eston *et al.,* 2005).

A subsequent study among 19 physically active men and women addressed the predictive success of the perceptually-regulated cycle protocol when two different lengths of exercise bouts were employed (Eston *et al.,* 2006). In a repeated measures design, the same five self-regulated intensities as in the original study were employed, but this time each intensity level was maintained for either two or four minutes. It was suggested that the two-minute trial was superior due to the lower limits of agreement achieved (-0.47 ± 7.44 $ml \cdot Kg^{-1} \cdot min^{-1}$), with the mean value being closer to actual $\dot{V}O_2max$ by <1.0 $ml \cdot Kg^{-1} \cdot min^{-1}$ (though no LoA were provided for the four-minute trial making a full appraisal of the results difficult for the reader). A further study among samples of active and sedentary males and females (Faulkner, Parfitt & Eston, 2007), employing a similar research design to the two previous studies, reported that $\dot{V}O_2max$ was significantly ($p < 0.05$) overestimated (6%) by data being extrapolated up to RPE 20, although not so when extrapolated to RPE 19. This was explained by the fact that the theoretical maximal RPE 20 is infrequently reported at volitional exhaustion, a phenomenon demonstrated previously (St Claire Gibson *et al.,* 1999; Kay *et al.,* 2001; Eston *et al.,* 2007). The prediction of $\dot{V}O_2max$ was not moderated by sex or physical activity status, although the overall LoA were slightly wider (trial 3 = 0.4 ± 8.4 $ml \cdot Kg^{-1} \cdot min^{-1}$) than previous studies had reported. Again, it was evident that practice improved

the prediction as trial three provided the best agreement and also the consistency of the prediction improved across the trials (T1–T2 = -1.2 ± 10.9 and T2–T3 = -0.4 ± 8.4 $ml \cdot Kg^{-1} \cdot min^{-1}$. The improvements were attributed to a greater proportional increase in work rate across the trials especially at the lower-moderate RPE levels (9–15). Notably this was significantly greater in the sedentary participants (Figure 2.6).

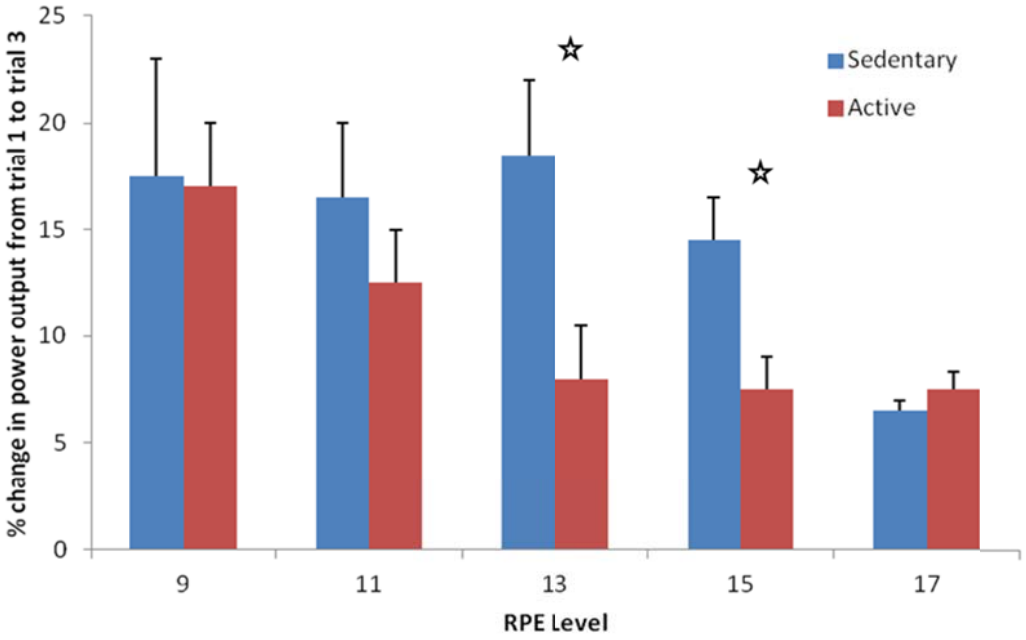


**Figure 2.6** Absolute and relative change in power output (SEM) from trial 1 to trial 3 of RPE production tests (*significant difference between groups, $p < 0.05$; re-drawn from Faulkner *et al.,* 2007).

This demonstrates the importance of practice on the so-called teleo-anticipatory mechanism for all individuals (St Clair-Gibson *et al.,* 2006), but especially so for sedentary populations who lack the regular experience of controlling their pace in

moderate to vigorous exercise. Sedentary individuals may need more time to become more familiar with the signals of exertion emanating from cardiorespiratory, metabolic and thermal changes associated with increases in exercise intensity (Faulkner *et al.,* 2007). This study also predicted $\dot{V}O_2$max from age-predicted maximum heart rate (LoA = 0.0 ± 11.6 $ml \cdot Kg^{-1} \cdot min^{-1}$) and demonstrated that the PRET was as good a predictor, if not more accurate. Similar findings to the previous studies were also observed in middle-aged sedentary males, this time during a discontinuous perceptually-regulated protocol, although the LoA were wider (2.4 ± 9.9 $ml \cdot Kg^{-1} \cdot min^{-1}$) than the original two investigations (Eston, Lambrick, Sheppard & Parfitt, 2008).

## 2.5 Conclusions and recommendations

The studies investigating the efficacy of perceptually-regulated exercise protocols for predicting exercise capacity, particularly $\dot{V}O_2$max, have thus far provided promising findings. However, it is evident that there are certain inconsistencies and oversights that make the field worthy of further scrutiny. For example, all previous investigations have used incremental protocols, so it was quite clear to the participants that they should add more resistance when asked to perform at the next RPE level. To test the integrity of the protocol, a randomisation of the RPE levels would be necessary. It was also outstanding that no production-specific instructions for the RPE scale were provided to participants. Instead, it was apparent that the estimation-specific instructions, as described by Borg (1998), were the ones adopted. It is quite likely that instructions written for applying the

RPE scale in production mode will improve the exerciser's understanding of the task requirements and their regulation of exercise intensity, and consequently the prediction of $\dot{V}O_2$max. Furthermore, that most studies have provided a GXT (to maximum) prior to administering production trials meant that their participants were exposed to the full perceptual range and by default provided with 'exercise' anchoring. This is situation that typically would not occur in non-laboratory or clinical environments. Arguably, therefore, new studies should perform the GXT (if needed) at the end, and following production trials which are preceded exclusively by the 'memory' anchoring procedure.

Further scope for investigation lies in the fact that no mode of exercise other than cycle ergometry had been investigated, and considering walking is the predominant mode of exercise for most people, it would be logical for perceptually-regulated treadmill exercise to be considered. In addition, although classed as a 'sub-maximal' intensity, requiring participants to regulate their exercise at RPE 17 is possibly undesirable given it represents strenuous effort and probably unsafe in untrained and clinical populations. Accordingly, an upper level of RPE 15 might be more suitable, especially as this is the termination point of many sub-maximal tests (Sykes, 2004) and being the upper exercise intensity recommended for clinical populations (BACR, 1995; ACSM, 2010) for safety reasons. Moreover, an examination of the suitability of a perceptually-regulated protocol among such populations (e.g. cardiac patients) for whom heart rate may be affected by medications, has obvious merit.

# Chapter 3

# Study 1

## Predicting maximal oxygen uptake via a perceptually-regulated exercise test (PRET)

Aspects of this chapter have previously been communicated at the European College of Sports Science (ECSS) Annual Congress (Portugal, 2008) and published in the *Journal of Exercise Science and Fitness* (2009; see Appendix 1).

### 3.1 Abstract

Recent research has yielded encouraging, yet inconsistent findings concerning the validity and reliability of predicting maximal oxygen uptake ($\dot{V}O_2max$) from a graded perceptually regulated exercise test (PRET). Accordingly, the purpose of the present study was to re-visit the validity and reliability of this application of ratings of perceived exertion using a modified PRET protocol. Twenty three volunteers (31 ± 9.9 years) completed four counter-balanced PRETs (involving two 2 min and two 3 min bouts administered over nine days, each separated by 48 h) on an electromagnetically braked cycle ergometer and one maximal graded exercise test (GXT). Participants self-regulated their exercise at RPE levels 9, 11, 13, 15 and 17 in a randomised order. Oxygen uptake ($\dot{V}O_2$) was recorded continuously during each bout. The $\dot{V}O_2$ values for the RPE ranges 9-17, 9-15 and 9-13 were extrapolated to RPE 20 using regression analysis to predict individual $\dot{V}O_2max$ scores. The concordance of the predicted and actual $\dot{V}O_2max$ scores and the trial-to-trial reliability of the predicted scores were analysed using the limits of agreement (LoA) technique. The LoA between actual (41.5 ± 8.0 $ml \cdot kg^{-1} \cdot min^{-1}$) and predicted $\dot{V}O_2max$ scores for the RPE range 9-17 were -2.6 ±10.1 and -1.3 ± 7.4 $ml \cdot kg^{-1} \cdot min^{-1}$ (2 min bout) and -1.0 ± 9.2 and 0.2 ± 7.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (3 min bout) for trials 1 and 2, respectively. Reliability analysis yielded LoA of -1.3 ± 9.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (2 min) and -0.8 ± 5.7 $ml \cdot kg^{-1} \cdot min^{-1}$ (3 min). The modified PRET provided acceptable and repeatable estimates of $\dot{V}O_2max$, suggesting its application in environments where maximal tests are inappropriate is worthy of further investigation.

### 3.2 Introduction

The utility of ratings of perceived exertion (RPE) as a means of self-regulating exercise intensity has been the subject of many investigations over the last three decades (e.g. Buckley *et al.,* 2000; Kang *et al.,* 1998; Eston & Thompson 1997; Marriott & Lamb 1996; Dunbar *et al.,* 1992; Ceci & Hassmen 1991; Chow & Wilmore 1984; Smutok *et al.,* 1980), principally due to its potential to facilitate exercise training that is considered to be both safe and beneficial (in health and fitness terms). Moreover, the application of RPE in this so-called production mode lends itself to the regulation of exercise intensity in non-clinical environments which lack the availability of sophisticated laboratory-based monitoring procedures.

On the basis that a body of evidence has confirmed the validity of perceptually regulated exercise in different modes of exercise, attention has recently been afforded to examining the merit of applying such exercise for predicting maximal oxygen uptake ($\dot{V}O_2$max). In the first of four recently published studies on this theme, Eston *et al.* (2005) demonstrated that amongst a small group (*n* = 10) of active, young males $\dot{V}O_2$max values predicted from a discontinuous, sub-maximal, perceptually regulated (or guided) exercise protocol involving 5 x 4-minute bouts incrementally from RPE 9-17, were at worst within ± 6 $ml \cdot kg^{-1} \cdot min^{-1}$ of actual $\dot{V}O_2$max values measured during an exhaustive cycle test. The authors concluded that whilst further validation studies were warranted, their findings had formed the basis for a perceptually-regulated exercise test (PRET) that could be used amongst groups for whom maximal exercise testing was undesirable. Accordingly,

the next three papers report on similar studies in which methodological manipulations of the PRET were introduced. In particular, these manipulations focused upon the length of the exercise bouts (two, three or four minutes) and the continuous/discontinuous nature of the PRET protocol. In the study by Eston *et al.* (2006), active males (*n* = 10) and females (*n* = 9) engaged in four PRETs that now involved repeat trials of 2- and 4-minute bouts of continuous cycle ergometry. Whilst their conclusions were generally supportive of the criterion validity of the PRET, specifically it was suggested that the 2-minute bout protocol was superior to the 4-minute one.

A subsequent investigation (first published on-line in 2007) among sedentary males (*n* = 13) utilised a PRET incorporating incremental cycling bouts lasting four minutes, but this time interspersed with four-minute periods of active recovery (Eston *et al.,* 2008). Though the findings revealed the best agreement between predicted and actual $\dot{V}O_2$max values in this situation (± 9.9 $ml \cdot kg^{-1} \cdot min^{-1}$) was less than that in the previous studies, the authors suggested that this was owing to the low fitness and sedentary nature of the participants. A further study by Faulkner *et al.* (2007) compared the validity of the PRET among active and sedentary males and females during cycle ergometry exercise. The protocol design comprised a continuous 3-minute PRET across five RPE intensities (9, 11, 13, 15 & 17). The principal finding was that the predictive accuracy of their protocol was not moderated by the activity status of the participants. Importantly, Faulkner *et al*'s (2007) study did also highlight factors that might impact upon the possible success

of PRETs, such as whether the prediction model should extend to RPE 19 or 20, or exclude data from the bouts at RPE 15 or 17.

It is evident that albeit in its infancy, research addressing the success of PRETs in predicting $\dot{V}O_2max$ has been confounded by methodological manipulations. In addition, the details of the standardised instructions for employing the RPE scale in production mode have not been presented in these studies, and it is this researcher's view that this needs to be resolved. Accordingly, there was encouragement to re-visit the initial validation scenario and make refinements to the methodology. Therefore the purpose of this study was to examine the validity of an improved sub-maximal PRET for predicting $\dot{V}O_2max$. In addition, the study set out to quantify the reproducibility of these predictions on a test-retest basis.

## 3.3 Method

### 3.3.1 Participants

Sixteen healthy male (29.2 ± 9.6 years, 75.4 ± 12.4 kg, 173 ± 24 cm) and seven female (36 ± 9.8 years, 70.4 ± 9.4 kg, 163 ± 12 cm) volunteers were recruited from a University population and local fitness club to take part in the study (Appendix 3). After receiving oral and written explanation of the study (Appendix 7), all participants gave their written consent (Appendix 11) to participate and prior to each testing session completed a pre-test health status questionnaire (Appendix

6). Ethical approval for the study was granted by the University's Faculty of Applied and Health Sciences Research Ethics Committee (Appendix 4).

### 3.3.2 Procedures

The study utilised a repeated measures design in which each participant was required to attend the laboratory on five separate occasions (48-72 hours apart), four times to perform a discontinuous sub-maximal perceptually regulated exercise test (PRET) and one further time to perform a graded exercise test to exhaustion ($\dot{V}O_2$max test). The PRETs involved repeated protocols with 2 min or 3 min bouts performed in a counterbalanced manner (to off-set order effects). The $\dot{V}O_2$max test did not precede the four PRETs since it was considered that this would provide a familiarisation to the full perceptual range of the RPE scale which would not be experienced by populations for whom this protocol will be particularly useful (e.g. clinical or sedentary). All exercise testing was conducted on an electronically braked cycle ergometer (Lode Corival, Gronigan, Netherlands) at a cadence maintained in the range 50-80 revs·min$^{-1}$. All data on the cycle's display screen (such as the power output and HR) were obscured from view at all times. Oxygen uptake and heart rate were recorded constantly during each exercise session via breath-by-breath online gas analysis (Oxycon, Jaeger, Germany) and a Polar wireless chest strap (Polar s810i, Finland) linked to the gas analyser. An automated gas and volume calibration was performed prior to each testing session in accordance with the manufacturer's guidelines. Participants were asked to

refrain from vigorous exercise (48hrs), alcohol (48hrs), tobacco (3hrs) and caffeine (12hrs) before each testing session.

### 3.3.3 Perceptually regulated sub-maximal graded exercise test

Immediately preceding each PRET, participants were presented with 6-20 RPE scale (Borg 1998) and were read a set of instructions by the investigator for its application during the exercise trial. These instructions are novel and were written by the researcher and one of his supervisors in an attempt to reflect the use of the scale in this study, that is, in its production rather than its estimation mode. Specifically:

> "During the following exercise I want you to regulate (adjust) the intensity by your overall perception, or feeling, of the level of exertion. *You* will determine how hard it feels, but I will give you targets to reach.
>
> I want you to use this rating scale [show Borg 6-20 scale] to help you adjust the exercise intensity to certain levels (ratings) that I will prescribe for you. You will instruct me to increase or decrease the intensity (resistance). You can see on the rating scale that number 6 is an intensity that means no exertion (effort) at all, whilst number 20 means a maximal effort. The numbers in between these extremes represent different levels of effort. For example, number 9 means a very light effort; for a normal healthy person it is like walking or cycling at a comfortable pace for quite a while. Number 13 means the exercise is getting somewhat hard, but it still feels OK to continue. Number 17 means exercise that is very strenuous. A healthy person can still go on, but he/she really has

> to push him/herself as it now feels 'heavy'. Number 19 is an extremely strenuous exercise level; for many people this is the most strenuous exercise they have ever experienced.
>
> Look at the scale and familiarize yourself with the numbers and words. When we are ready to begin, I'll ask you to exercise at a level that matches one of the numbers on the scale. You will be given some time to adjust the intensity until you reach a level that you feel (perceive) matches that number. Please focus on your *overall* feelings, not just your legs or breathing. Then you will exercise at that level for 2 minutes [or 3 minutes].
>
> After this first bout, I'll let you rest for a short while and then I'll give you another target number to exercise at. This may be a higher or lower number than the first one. You will then instruct me to adjust the exercise intensity as before, to match the new number and exercise at that level for another 2 minutes [or 3 minutes]. After another short rest, I will ask you to repeat this procedure three more times at different effort levels.
>
> Please be aware that I do not have any expectations about your performance during the session and remember that my main interest is that you use your own feelings of effort to control the exercise intensity."

Following this, each PRET protocol required participants to regulate their exercise intensity to match five RPE levels (9, 11, 13, 15 and 17) prescribed by the investigator in an individually randomised order. Participants commenced cycling at a light resistance (50 W) and continued for five minutes before being instructed to produce an exercise intensity equivalent to the initial effort rating selected by the

investigator. The exercise intensity was then adjusted by the investigator according to the participants' instructions using the control panel on the cycle. Participants were given up to three minutes to adjust the exercise intensity to their satisfaction (which matched the prescribed level), at which time their expired air was recorded for either two or three minutes (depending on the particular PRET they were engaged in). One minute into the recording participants were asked to verify their selection and if necessary were allowed a final refinement of the self-regulated intensity. At the end of the bout, the exercise resistance was removed and the participant was instructed to continue pedalling slowly for three minutes. This procedure was repeated for the other four RPE levels. The mean oxygen uptake and heart rate during the final 30 seconds of each RPE level in all bouts were calculated.

### 3.3.4 $\dot{V}O_2$max protocol

The graded exercise test (GXT) required participants to perform a light five-minute warm-up (on the same electromagnetically braked cycle used for the previous four PRETs), followed by an incremental continuous protocol starting at 50 W and increasing by 50 W every three minutes until volitional exhaustion. The establishment of $\dot{V}O_2$max for each participant was evaluated by the criteria set out by Bird and Davidson (1997) and confirmed if four of the following criteria where met: subjective fatigue and volitional exhaustion, a plateaux in $\dot{V}O_2$, RPE of 19-20, HR within ± 10 beats of age-related maximum, lactate >8 mmol·$L^{-1}$ and RER >1.15.

### 3.3.5 Data Analysis

Following a check on the normality of their distributions via the Shapiro-Wilk, descriptive statistics (mean ± SD) were computed for $\dot{V}O_2$ values across all five exercise trials. In the manner of Eston *et al.* (2005), individual linear regression analysis was performed on each participant's five $\dot{V}O_2$ values (from RPE levels 9, 11, 13, 15 and 17) to predict their GXT determined $\dot{V}O_2$max at an RPE of 20 using the equation $\dot{V}O_2$max = a + b (RPE 20). Additionally, for comparative purposes, the same analysis was conducted on truncated RPE ranges, that is, on $\dot{V}O_2$ data generated from RPE 9-13 and RPE 9-15. The agreement between the criterion $\dot{V}O_2$max values and the predicted values from the PRET were calculated with the 95% limits of agreement (LoA) technique (Bland & Altman, 1986). The LoA technique was also employed to assess the reproducibility of the $\dot{V}O_2$max predictions from trial 1 to trial 2, with the addition of the intraclass correlation coefficient (ICC), calculated via a two-way mixed effects model for absolute agreement. All data analysis was conducted using SPSS for windows (version 14.0) and alpha was set at the 0.05 level.

## 3.4 Results

The mean $\dot{V}O_2$max from the graded exercise test was 41.5 (± 8.0) ml·kg$^{-1}$·min$^{-1}$. Relative $\dot{V}O_2$ values are presented in Table 3.1 at each RPE level across two trials for both the 2 min and 3 min bouts. In each PRET trial, increases in RPE level were accompanied by significant increases in mean $\dot{V}O_2$ ($F = 177.07$, df =

1.3, $p < 0.0005$; Table 3.1 & Figure 3.1), HR (F = 0.224.06, df = 2.0, $p < 0.0005$; Table 3.2) and power output (F = 217.79, df = 1.3, $p < 0.0005$; Table 3.3).

**Table 3.1** Mean (± SD) oxygen uptake values ($ml \cdot kg^{-1} \cdot min^{-1}$) across two trials for 2 min and 3 min PRETs.

| RPE level | 2 min bout | | 3 min bout | |
|---|---|---|---|---|
| | **Trial 1** | **Trial 2** | **Trial 1** | **Trial 2** |
| **9** | 11.4 ± 3.0 | 11.5 ± 2.9 | 11.0 ± 2.5 | 11.6 ± 2.9 |
| **11** | 15.4 ± 4.5 | 15.7 ± 3.4 | 14.9 ±2.6 | 15.2 ± 3.6 |
| **13** | 19.4 ± 4.5 | 21.1 ± 4.9 | 20.9 ± 4.2 | 21.6 ± 5.0 |
| **15** | 25.7 ± 6.7 | 25.9 ± 6.4 | 26.5 ± 5.7 | 27.0 ± 6.0 |
| **17** | 31.9 ± 8.7 | 32.5 ± 7.7 | 31.5 ± 7.7 | 33.1 ± 8.8 |
| **Criterion $\dot{V}O_2$max** | 41.5 ± 8.0 | | | |
| **Predicted $\dot{V}O_2$max** | 38.9 ± 10.7 | 40.2 ± 9.6 | 40.5 ± 10.4 | 41.3 ± 9.9 |

Neither the effect of trial x RPE level interaction on $\dot{V}O_2$ (F = 1.23, df = 4.0, p = 0.31), HR (F = 2.22, df = 2.0, $p = 0.12$) or power output (F = 0.62, df = 3.3, $p = 0.65$) was significant, nor was the bout x trial x RPE level interaction (F = 1.54, df = 3.0, $p = 0.21$; F = 0.99, df = 2.5, $p = 0.40$; F = 1.91, df = 2.6, $p = 0.15$), reflecting consistency in the intensity of the PRETs. Individual zero order correlations from the regression analyses of RPE and $\dot{V}O_2$ (bouts 9-17) all exceeded 0.90, except one ($r = 0.65$; 2 min, trial 1), and were typically 0.94 and above. The correlations

based on bouts 9-15 exceeded 0.83, except one ($r$ = 0.31; 2 min trial 1), whereas those based on bouts 9-13 were all above 0.42. The means of the predicted $\dot{V}O_2$max values for the 9-17 PRET were not significantly different ($p$ > 0.05) to the criterion $\dot{V}O_2$max value (see Table 3.4), although there was a significant difference for both trials of the 2 min 9-15 bout and trial one of the 9– 3 2 min bout.

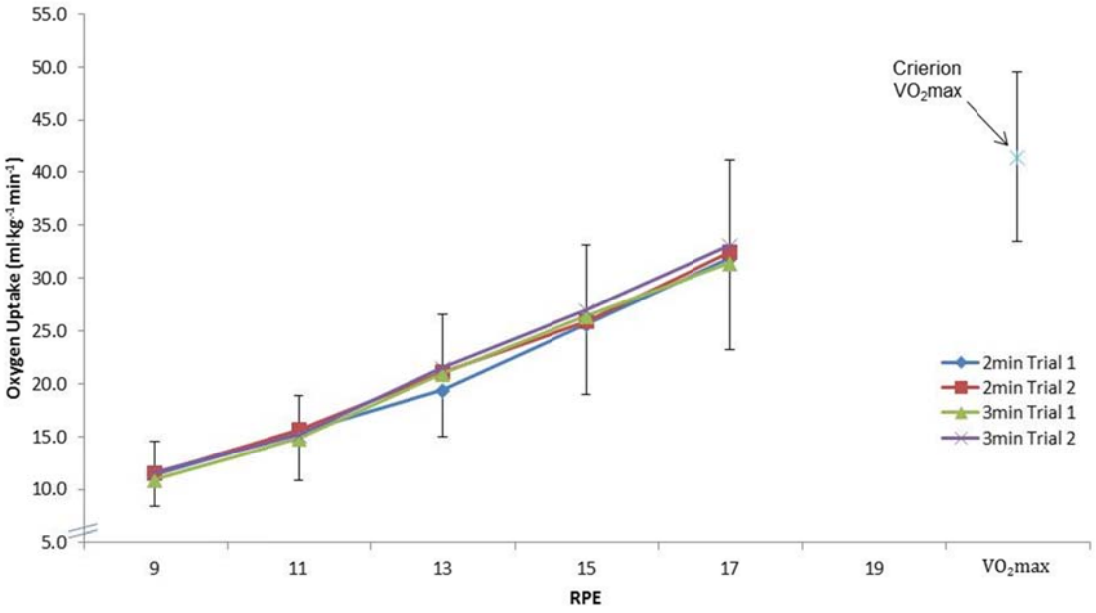


**Figure 3.1** Oxygen uptake values (ml·kg$^{-1}$·min$^{-1}$) across two trials for 2 min and 3 min PRETs demonstrating a linear relationship and criterion $\dot{V}O_2$max.

The 95% LoA statistics (bias ± 1.96 x $SD_{diff}$) calculated on the basis that the errors (differences) were found to be normally distributed and homoscedastic (Bland & Altman, 1986), were superior for the full RPE range (9-17) than the truncated ranges, and narrowest in the second trial of the 3 min PRET (Table 3.4 & Figure 3.2). The statistics in Table 3.5 show the reproducibility of predicted $\dot{V}O_2$max calculated from the full data set (9-17) and the 9-15 range to be better in

the 3 min PRET than in the corresponding 2 min bout, as reflected by higher ICCs and narrower LoA. Expressed as a proportion of the overall mean of the two trials, the random (within-subjects) error in the 9-17 RPE range (3 min bout) equates to a worse case variability of up to ± 14%. The corresponding statistics for the truncated ranges of 9-15 and 9-13 were ± 26% and ± 36%, respectively.

**Table 3.2** Mean (± SD) heart rate (beats·min$^{-1}$) across two trials for 2 min and 3 min PRETs.

| RPE level | 2 min bout | | 3 min bout | |
|---|---|---|---|---|
| | **Trial 1** | **Trial 2** | **Trial 1** | **Trial 2** |
| **9** | 96 ± 17.3 | 92 ± 22.1 | 96 ± 15.2 | 95 ± 16.8 |
| **11** | 108 ± 20.2 | 108 ± 18.6 | 104 ± 17.2 | 105 ± 17.0 |
| **13** | 118 ± 19.3 | 123 ± 21.8 | 122 ± 20.2 | 121 ± 20.7 |
| **15** | 133 ± 19.9 | 138 ± 21.8 | 135 ± 22.5 | 136 ± 20.1 |
| **17** | 148 ± 20.9 | 150 ± 20.0 | 149 ± 21.6 | 151 ± 21.3 |

**Table 3.3** Mean (± SD) power output (W) across two trials for 2 min and 3 min PRETs.

| RPE level | 2 min bout | | 3 min bout | |
|---|---|---|---|---|
| | **Trial 1** | **Trial 2** | **Trial 1** | **Trial 2** |
| **9** | 39 ± 13.9 | 43 ± 15.7 | 38 ± 9.9 | 45 ± 17.0 |
| **11** | 68 ± 22.5 | 75 ± 22.5 | 67 ± 17.0 | 70 ± 21.2 |
| **13** | 101 ± 22.0 | 115 ± 29.3 | 108 ± 26.1 | 113 ± 28.0 |
| **15** | 142 ± 38.5 | 148 ± 34.7 | 141 ± 35.1 | 149 ± 35.9 |
| **17** | 185 ± 52.7 | 192 ± 50.2 | 181 ± 50.1 | 190 ± 47.1 |

**Table 3.4** Validity of the PRET (95% LoA, $ml \cdot kg^{-1} \cdot min^{-1}$) predicted $\dot{V}O_2max$ values calculated for three RPE ranges.

| Exercise trial | RPE range | | |
|---|---|---|---|
| | **9 - 17** | **9 - 15** | **9 – 13** |
| **Trial 1 - *2 min bout*** | -2.6 ± 10.1 | -4.6* ± 11.2 | -7.4 * ± 14.4 |
| **Trial 2 - *2 min bout*** | -1.3 ± 7.4 | -2.6* ± 10.7 | -3.8* ± 12.2 |
| **Trial 1 - *3 min bout*** | -1.0 ± 9.2 | -1.1 ± 10.7 | -0.5 ± 19.3 |
| **Trial 2 - *3 min bout*** | -0.2 ± 7.2 | -0.4 ± 10.8 | -0.8 ± 15.1 |

*significant bias ($p < 0.05$)

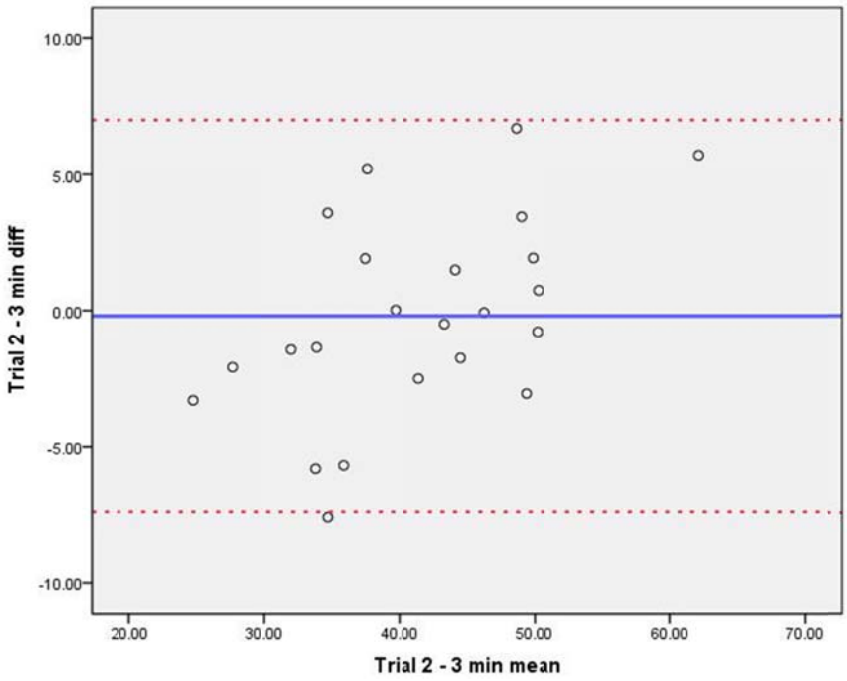


**Figure 3.2** Bland-Altman plot demonstrating the optimal LoAs for RPE 9–17 trial 2 of the 3-minute bout.

**Table 3.5** Reliability of $\dot{V}O_2$max predictions across two trials for 2 min and 3 min PRETs at three RPE ranges.

| Exercise trial | RPE range | | | | | |
|---|---|---|---|---|---|---|
| | 9 - 17 | | 9 - 15 | | 9 - 13 | |
| | ICC | 95% LoA[1] | ICC | 95% LoA[1] | ICC | 95% LoA[1] |
| **2 min bout** | .90 | -1.3 ± 9.2 | .80 | -2.0 ± 11.9 | .70 | -3.6* ± 13.5 |
| **3 min bout** | .96 | -0.8 ± 5.7 | .93 | -0.7. ± 7.3 | .77 | -0.3 ± 15.2 |

*significant bias ($p < 0.05$)

[1]$ml \cdot kg^{-1} \cdot min^{-1}$

### 3.5 Discussion

The modified PRET used in the current study has provided data which reinforce the validity of predicting maximal oxygen uptake from sub-maximal, perceptually-regulated exercise. The optimal estimates of $\dot{V}O_2$max (within ± 7.5 $ml \cdot kg^{-1} \cdot min^{-1}$ of criterion values) are higher than those reported in the original study (Eston *et al.,* 2005) but superior to those in subsequent investigations (Eston *et al.,* 2008; Faulkner *et al.,* 2007; Eston *et al.,* 2006). Whilst this finding might be due to our development and manipulations of the PRET, it is possible that differences between the samples of participants could also be responsible. However, it is anticipated that the merit of this study will be manifest in future research and applications of the PRET, such as in prescribing individualised training or rehabilitation programmes.

Participants in the current study demonstrated individually and as a sample (see Table 3.1) that they could successfully regulate their exercise intensities across a broad range during the 2 and 3 min PRETs. That they could do this with exercise bouts that were not incrementally prescribed, as in previous investigations (Eston *et al.,* 2008; 2006; 2005) is impressive. For one participant, the strong linearity of the RPE-$\dot{V}O_2$ relationship was not demonstrated in the first 2 min PRET only, though this was likely due to the novelty of the experience since the correlation between RPE and $\dot{V}O_2$ exceeded 0.91 in the three subsequent PRETs. Moreover, that everyone was able to apply the scale appropriately, is reassuring that the revised instructions administered prior to each bout were facilitating. In the same vein, amending the PRET to provide the opportunity for participants to verify

or adjust their self-selected intensity on one further occasion one minute into each bout was seen to be a useful inclusion as over half (52%) of them elected to do so in one or more of the bouts. Of those who did, adjustments of 7.0 ± 2.6 W (trial 1; 2 min), 6.5 ± 5.3 W (trial 2; 2 min), 6.7 ± 6.2 W (trial 1; 3 min) and 2.8 ± 5.8 W (trial 2; 3 min) were made. In most instances, the adjustments were made during the higher intensities (RPE 15 and 17), and more often during the longer bouts.

In relative terms, the 'acceptability' of the predictions of $\dot{V}O_2$max from the current PRET (2 min or 3 min) sits well with those generated from the few previous studies of this kind. Comparable data involving other modes of exercise do not exist, and comparisons with other sub-maximal predictive methods, such as those reliant on heart rate responses, are compromised by the tendency of researchers to use bi-variate correlations or tests of mean difference to quantify the criterion validity of their methods. Had this study been reliant on this statistical approach, then it would be advocating without hesitation the virtue of the 9-17 sub-maximal protocol (as the correlations between predicted and actual values were 0.89-0.94). However, by appropriately taking notice of the size of the within-subject agreement between estimated and actual $\dot{V}O_2$max values, the interpretation of validity has to be more measured. Researchers are meant to decide *a priori* what constitutes an acceptable level of agreement when addressing issues of validity and reliability, whether this is based on clinical significance – to provide a treatment or not (Bland & Altman, 1999; 1986) or analytical goals, such as whether the agreement is close enough for the method to be of practical use (Atkinson & Nevill, 1998). Arguably,

therefore, the optimal estimates of $\dot{V}O_2$max are suspect if the researcher or practitioner is pursuing absolute accuracy from the PRET. However, the estimates are superior or no worse to those reported for other sub-maximal predictive tests, such as the classic Astrand cycle test (Nevill & Atkinson, 2007) and the Chester step test (Buckley *et al.,* 2004), respectively. Moreover, if the focus is on reproducibility, and the need for a method that can be used for monitoring changes in aerobic capacity due to interventions, then the current data are more trustworthy. For 95% of the sample, the second 3 min PRET yielded estimates that were at worst approximately 6 $ml \cdot kg^{-1} \cdot min^{-1}$ higher or lower than the equivalent first PRET. For approximately 68% of the sample, a reference range described by the so-called 'typical error' calculation (Hopkins, 2000), the trial-to-trial agreement was three times as good (approximately 2 $ml \cdot kg^{-1} \cdot min^{-1}$). In order to demonstrate a 'real' (i.e. non-random) change in $\dot{V}O_2$max, therefore, a difference of at least 3, and preferably 7 $ml \cdot kg^{-1} \cdot min^{-1}$) would be necessary. Changes of such magnitude are, depending on the training status of the individual, likely to be observed with suitable training among healthy (Bouchard *et al.,* 1999) and cardiac (Swain & Franklin, 2002) populations.

It was noteworthy that the second trial for each bout produced more accurate predictions than the first (narrower limits of agreement), reinforcing previous evidence for a practice or familiarisation effect (Eston *et al.,* 2008; 2006, 2005; Buckley *et al.,* 2000). Moreover, the within-subjects error for the second 2 min PRET was remarkably comparable to the Eston *et al.* (2006) figure for the

second of their 2 min protocols (± 7.4 ml·kg$^{-1}$·min$^{-1}$) of incremental cycling. However, whereas Eston *et al.* (2006) argued (without reporting their 95% LoA) that the $\dot{V}O_2$max predictions from the 2 min protocol were more reproducible than their 4 min protocol, the longer of the current PRETs (3 min) was more reproducible than the shorter one. The likely, and perhaps unsurprising, explanation for this is that in contrast to the 3 min bouts, the $\dot{V}O_2$ values did not stabilise during the 2 min bouts, particularly at RPE 17, owing to the $\dot{V}O_2$ slow component delaying the attainment of a steady-state level (Xu & Rhodes, 1999). The narrower 95% LoA in the 3 min bout reflect that in a worst case scenario, a participant's estimate of, say, 40 ml·kg$^{-1}$·min$^{-1}$ in trial 1 could be as high as 46 or as low as 34 ml·kg$^{-1}$·min$^{-1}$ in trial 2. This compares favourably with the data from the recent studies of Faulkner *et al.* (2007) and Eston *et al.* (2008) which used 3 min and 4 min incremental protocols, respectively. Using the above example, trial 2 estimates could have ranged from 50.4 to 27.2 ml·kg$^{-1}$·min$^{-1}$ (Faulkner *et al.,* 2007), or from 51.0 to 27 ml·kg$^{-1}$·min$^{-1}$ (Eston *et al.,* 2008). Interestingly, whilst both these studies reported improved reproducibility when a third trial was used, their 95% LoA remained wider than those achieved with the current two-trial PRET.

Consideration of the impact of truncating the RPE range on the predictions of $\dot{V}O_2$max is pertinent owing to the potential for utilising PRETs among populations for whom exercise to levels equating to "Very Hard" (RPE 17) are contra-indicated or inadvisable, such as cardiac patients, obese or sedentary participants. The protocols used in the current and previous studies of this kind

have included a bout at RPE 17, and then removed its data to derive a prediction model for the range 9-15. Similarly, ignoring that data from the RPE 15 bout has enabled extrapolations of $\dot{V}O_2$max for the range 9-13. The effects of such manipulations on the criterion validity of the current modified PRET are noteworthy, particularly when data from only three bouts (9, 11, and 13) are used. Although the situation is better for the 3 min than the 2 min PRETs in that the biases between criterion and predicted $\dot{V}O_2$max values remained non-significant (the mean values are similar), the magnitude of the within-subjects error from the 9-15 (± 10.8 ml·kg$^{-1}$·min$^{-1}$) and the 9-13 (± 15.1 ml·kg$^{-1}$·min$^{-1}$) predictions now reflect worst case differences of ± 26% and ± 36%, respectively. Compared to the optimal predictions based on the full data set (± 17%), these margins of error are excessive on an individual basis. However, had the predictions been made from data collected in PRETs that intentionally did not go beyond RPE 15, or RPE 13, it is possible that the self-regulated intensities for each bout would have been different. In this sense, it is possible to endorse the suggestion made by Faulkner *et al.* (2007) that participants' awareness of the protocol containing "Hard" and "Very Hard" bouts might have led them to under-regulate their efforts as part of a pacing strategy. Indeed, that the modified PRET enabled them to re-evaluate their chosen exercise intensity after one minute probably refined such a strategy given the bout's end-point was now closer. St Clair-Gibson *et al.* (2006) posit how such a strategy is governed by the brain's teleo-anticipatory centre which synthesises knowledge of task end-point with other inputs such as memory of prior events and knowledge of metabolic reserves. It would be interesting to observe what impact restricting the

PRET to an upper limit of RPE 15 (or 13) would have on such a strategy and the physiological responses that ensue.

In conclusion, the data from this study serve to reinforce the potential efficacy of a perceptually-regulated approach to estimating maximal oxygen uptake. In particular, the modifications made to the PRET (protocol and related documentation) provided a more valid test of a person's ability to apply the concept of perceived exertion in production mode than has been adopted before. The current participants could regulate their exercise output in a discontinuous protocol requiring 3 min bouts of self-regulated cycling well enough to facilitate reasonable, and reproducible, predictions of their $\dot{V}O_2$max. Given the body of knowledge now available, it is time to explore the utility of this technique in a more applied setting, for example, amongst people where maximal exercise testing is not practicable, such as in community health and rehabilitation settings.

# Chapter 4

# Study 2

## The validity and reliability of predicting maximal oxygen uptake from a treadmill-based sub-maximal perceptually-regulated exercise test

Aspects of this chapter have previously been communicated at the American College of Sports Medicine Annual Conference (Seattle, 2009) and published in the *European Journal of Applied Physiology* (2010; see Appendix 2).

## 4.1 Abstract

The purpose of this study was to determine for the first time whether $\dot{V}O_2$max could be predicted accurately and reliably from a treadmill-based perceptually regulated exercise test (PRET) incorporating a safer and more practical upper-limit of RPE 15 ("Hard") than used in previous investigations. Eighteen volunteers (21.7 ± 2.8 years) completed three treadmill PRETs (each separated by 48 h) and one maximal graded exercise test. Participants self-regulated their exercise at RPE levels 9, 11, 13 and 15 in a continuous and incremental fashion. Oxygen uptake ($\dot{V}O_2$) was recorded continuously during each three minute bout. $\dot{V}O_2$ values for the RPE range 9-15 were extrapolated to $RPE_{19}$ and $RPE_{20}$ using regression analysis to predict individual $\dot{V}O_2$max scores. The optimal limits of agreement (LoA) between actual (48.0 ± 6.2 $ml \cdot kg^{-1} \cdot min^{-1}$) and predicted scores were -0.6 ± 7.1 and -2.5 ± 9.4 $ml \cdot kg^{-1} \cdot min^{-1}$ for the $RPE_{20}$ and $RPE_{19}$ models, respectively. Reliability analysis for the $\dot{V}O_2$max predictions yielded LoAs of 1.6 ± 8.5 ($RPE_{20}$) and 2.7 ± 9.4 ($RPE_{19}$) $ml \cdot kg^{-1} \cdot min^{-1}$ between trials 2 and 3. These findings demonstrate that (with practice) a novel treadmill-based PRET can yield predictions of $\dot{V}O_2$max that are acceptably reliable and valid amongst young, healthy, and active adults.

## 4.2 Introduction

Maximal oxygen uptake ($\dot{V}O_2max$) is widely regarded as the criterion measure of cardiorespiratory fitness (ACSM, 2010) and a strong and independent predictor of mortality in patients with known cardiovascular disease (Aijaz *et al*., 2009; Kavanagh *et al*., 2002; Laukkanen *et al*., 2004). However, that its measurement has safety and cost implications has encouraged traditionally the use of numerous methods for predicting peak or $\dot{V}O_2max$ from sub-maximal exercise protocols. Typically, these have used heart rate responses to incremental exercise as the independent variable, but a persuasive case has been made in the last few years for predicting $\dot{V}O_2max$ from oxygen uptake values generated during a perceptually regulated exercise test (Eston *et al.,* 2005; 2006; 2008; Faulkner *et al.,* 2007; also Study 1 of this thesis).

The perceptually-regulated exercise test (PRET) utilises the Borg 6-20 RPE scale (Borg 1998) in its so-called production mode whereby the participant is requested to set their own exercise intensity in response to a range of prescribed RPE levels. Whilst utilising RPE in this way has been shown to be a valid and reliable means of self-regulating safe and effective exercise in a variety of modalities, such as cycle ergometry (Buckley *et al.,* 2000; Eston & Williams 1988; Kang *et al.,* 1998), treadmill running (Dunbar *et al.,* 1992; Eston *et al.,* 1987) and rowing ergometry (Marriott & Lamb 1996), research on the predictive capability of a PRET has thus far only employed cycle ergometry.

In the first study on this theme Eston *et al.* (2005) predicted $\dot{V}O_2max$ from an incremental cycling PRET protocol consisting of 4 min bouts at RPE 9, 11, 13, 15 and 17 to within ± 6 $ml \cdot kg^{-1} \cdot min^{-1}$ of actual values in a sample of ten active young males. Subsequent studies addressed the predictive success of the cycle PRET when different lengths of exercise bouts were employed (Eston *et al.,* 2006), among active versus sedentary male and female populations (Faulkner *et al.,* 2007), when a discontinuous protocol was used (Eston *et al.,* 2008), and when refined RPE instructions were provided (see Study 1 of this thesis). A common element to these studies though, is that the validity of the PRET was examined from $\dot{V}O_2$ values obtained during exercise that was prescribed across a broad sub-maximal perceptual range; from RPE 9 (Very light) to RPE 17 (Very hard). However, the upper-most level is considered too strenuous for sedentary and clinical populations (ACSM, 2010; AACVPR, 2006; BACR, 1995) and in acknowledging this limitation, the above studies tended to generate additional predictions of $\dot{V}O_2max$ that did not include the data from RPE 17 (i.e. RPE 9-15, or RPE 9-13) to explore if they were as accurate. Compared to the predictions based on the full data set (RPE 9-17), which at best reflect margins of error of ± 17% (Eston *et al.,* 2005; Study 1 of this thesis), the errors associated with the 9-15 (at best ± 23-26%, Eston *et al.,* 2005; Study 1 of this thesis) and 9-13 (± 35-36%, Faulkner *et al,.* 2007; Study 1 of this thesis) predictions were found to be notably larger, and excessive on an individual basis. However, it was posited previously in Study 1 that if data are collected from PRETs that purposely are limited in intensity to RPE 15 (or RPE 13), the accuracy of the $\dot{V}O_2max$ predictions might be better on

the basis that in the absence of an exercise protocol containing bouts labelled "Very hard" (or "Hard), the participants are less likely to under-regulate their exercise efforts as part of a pacing strategy, in the manner suggested by Faulkner *et al.* (2007).

There are therefore two key elements that need to be addressed: (i) the agreement of the PRET with different modes of exercise, and (ii) the agreement of the PRET when the exercise intensity is no greater than RPE 15 (Hard/heavy). In this context there is a case for exploring the validity and reliability of a treadmill-based PRET since a treadmill is a popular mode employed in exercise testing and usually produces higher $\dot{V}O_2$max values than a cycle ergometer. In addition, investigating a PRET whose upper limit is capped at RPE 15 (Hard), a value that is familiar in cardiac rehabilitation settings as a threshold for exercise effort and in general fitness screening situations (where it is utilised as a termination point in many sub-maximal tests) is justifiable as it lowers the health risk and ethical concerns associated with more strenuous or exhaustive exercise, reduces testing times and costs, and the degree of participant motivation required (Faulkner & Eston, 2008). Accordingly, the purpose of this study was to assess the criterion validity of predicting $\dot{V}O_2$max from sub-maximal $\dot{V}O_2$ values elicited during a truncated treadmill-based PRET (maximum RPE 15) and the reliability of the predictions over three repeat trials.

## 4.3 Method

### 4.3.1 Participants

Eighteen (14 male and 4 female) healthy active participants (21.7 ± 2.8 years, 71.21 ± 12.81 kg, 172 ± 0.1 cm) were recruited from a University population to take part in the study. After receiving oral and written explanation of the study (Appendix 8), all the volunteers gave their consent (Appendix 11) to participate and prior to each testing session completed a pre-test health status questionnaire (Appendix 6). Ethical approval for the study was granted by the Faculty of Applied and Health Sciences ethics committee at the University of Chester (Appendix 4).

### 4.3.2 Procedures

This study utilised a repeated measures design in which each participant was required to attend the laboratory on four separate occasions (48-72 h apart), three times to perform a continuous; incremental sub-maximal PRET and one further time to perform a graded exercise test to exhaustion ($\dot{V}O_2$max test). The PRETs were administered on three occasions since previous studies involving cycle ergometry have highlighted how practice improves the repeatability and accuracy of the $VO_2$max predictions (Eston *et al.,* 2005; 2006; Faulkner *et al.,* 2007; Study 1 of this thesis). The $\dot{V}O_2$max test was performed subsequent to the three PRETs as it was considered that this would avoid participants being sensitised to the full perceptual range of the RPE scale (up to RPE 20), which would not occur in environments for which sub-maximal tests might be particularly useful (e.g. clinical or sedentary). All exercise testing was conducted on a

motorised treadmill (Woodway PPS55 Sport-I Treadmill), which had its display screen concealed from participants so that no external feedback relating to exercise intensity (speed, gradient and HR) was available. Oxygen uptake and heart rate were recorded continuously during each exercise testing session via breath-by-breath online gas analysis (Oxycon, Jaeger, Germany) and Polar wireless telemetry (Polar s810i, Finland). An automated gas and volume calibration was performed prior to each testing session in accordance with the manufacturer's guidelines. Each participant was tested at a time of day similar to their previous test/s (within 2 h) to control for physiological variation caused by circadian rhythms (Reilly, 2007). Participants were asked to refrain from vigorous exercise (48hrs), alcohol (48hrs), tobacco (3hrs) and caffeine (12hrs) before each testing session.

### 4.3.3 Sub-maximal treadmill perceptually regulated exercise test (PRET)

Before performing each PRET, participants were presented with the 6-20 RPE scale (Borg 1998) and read out a set of instructions (see Study 1) for its application during the exercise trial. These instructions were specific to using the RPE scale in its production rather than estimation mode. Following this, each PRET protocol required participants to regulate their intensity to match four RPE levels (9, 11, 13 and 15) prescribed by the investigator in an incremental order. Participants commenced walking at a speed of 1.3 $km \cdot h^{-1}$ for three minutes before being instructed to produce an exercise intensity equivalent to RPE 9 (very light) on the RPE scale. The exercise intensity was then adjusted by the researcher on instruction from the participant using the control panel on the treadmill. The intensity was first altered via an increment in speed of 1.3 $km \cdot h^{-1}$ and secondly by

an increase in gradient of 0.5% on request from the participant. This was performed to elicit a change in intensity of approximately 0.2 - 0.6 METS per instruction from the participant. Participants were given three minutes to adjust the exercise intensity to their satisfaction (which matched RPE level 9, very light), at which time their expired air was analysed for the following three minutes. One minute into the recording participants were allowed a final refinement of the self-regulated intensity. This procedure was then repeated for RPE levels 11, 13 and 15. The mean oxygen uptake and heart rate during the final 30 seconds of each RPE level in all bouts were calculated. Upon completion of the PRET a warm down was performed at 5 $km \cdot h^{-1}$ until heart rate dropped below 100 $b \cdot min^{-1}$.

### 4.3.4 $\dot{V}O_2$max protocol

$\dot{V}O_2$max was determined via the Bruce protocol (Bruce *et al.,* 1973), a graded exercise test (GXT) which employs a continuous and incremental procedure, starting at a speed of 2.74 $km \cdot h^{-1}$ and a gradient of 10%, increasing in gradient by 2% every 3 min in-line with simultaneous increments in speed of 2.74, 4.02, 5.47, 6.76, 8.05 and 8.85 $km \cdot h^{-1}$. Expired air and HR were monitored in the manner described above, with the addition of blood lactate measured immediately after the cessation of the last stage (Lactate Pro, Arkray Japan). The establishment of $\dot{V}O_2$max for each participant was evaluated by the criteria set out by Bird and Davidson (1997) on behalf of the British Association of Sport and Exercise Sciences - subjective fatigue and volitional exhaustion, a plateau in $\dot{V}O_2$, RPE 19 or 20, HR within ± 10 beats of age-related maximum, post-exercise lactate >8

$mmol \cdot l^{-1}$ and a respiratory exchange ratio >1.15 – and confirmed if four of them were met. These criteria are reported widely in laboratories across the UK and reported frequently in the applied physiology literature. Nonetheless it is noted that future research might need to reappraise the use of the *secondary criteria* as a means of validating the attainment of a maximal oxygen uptake in light of the findings from a recent study of active males by Poole *et al.,* (2008) which demonstrated their tendency to incorrectly reject the occurrence or under-estimate the values of $\dot{V}O_2max$.

### 4.3.5 Data Analysis

Following a check on the normality of their distributions via the Shapiro-Wilk statistic, descriptive statistics (mean ± SD) were computed for $\dot{V}O_2$ values across all four exercise trials. In the manner of Faulkner *et al.* (2007), individual linear regression analyses ($\dot{V}O_2$ = a + *b* (RPE)) were performed on each participant's four measured $\dot{V}O_2$ values (from RPE levels 9, 11, 13, and 15) to predict their GXT determined $\dot{V}O_2max$ at the typical ($RPE_{19}$) and theoretical ($RPE_{20}$) end-points. Separate one-way repeated measures ANOVAs were used for each predictive model to compare trial means to actual $\dot{V}O_2max$ scores, followed up, where appropriate, with Bonferroni adjusted paired *t*-tests to locate differences between specific means. The agreement between the criterion $\dot{V}O_2max$ values and those predicted from the PRETs were calculated with the 95% limits of agreement (LoA) technique, on the basis that the errors (differences) were found to be normally distributed and homoscedastic (Bland & Altman 1986). The LoA (bias ± 1.96 x

$SD_{diff}$) technique was also employed to assess the reproducibility of the $\dot{V}O_2$max predictions across the three trials, with the addition of the typical error ($SD_{diff}$ / √2; Hopkins, 2000), and the intraclass correlation coefficient (ICC), calculated via a two-way mixed effects model for absolute agreement. All data analysis was conducted using SPSS for Windows (version 16.0) and alpha was set at the 0.05 level.

### 4.4 Results

All the participants satisfied the criteria for achieving $\dot{V}O_2$max during the GXT and the mean $\dot{V}O_2$max for the sample was 48.0 ± 6.2 $ml \cdot kg^{-1} \cdot min^{-1}$. Of note was that everyone reported a terminal RPE of 19. In each PRET trial, increases in RPE level were accompanied by significant increases in mean $\dot{V}O_2$ ($F = 117.20$, $df = 1.7$, $p < 0.0005$; Table 4.1) and HR ($F = 189.0$, $df = 1.3$, $p < 0.0005$; Table 4.2). Neither the effect of trial on both $\dot{V}O_2$ ($F = 0.80$, $p = 0.41$) or HR ($F = 3.56$, $p = 0.06$) was significant, nor was the trial x RPE level interaction ($F = 2.75$, $df = 1.6$, $p = 0.09$; $F = 2.17$, $df = 3.1$, $p = 0.10$), reflecting consistency in the intensity of the PRETs. All individual correlations from the regression analyses of RPE and $\dot{V}O_2$ (levels 9-15) exceeded 0.91, except two (0.80, trial 1; 0.78, trial 3), and were typically 0.96 or higher.

The mean differences in $\dot{V}O_2$max between the measured and the PRET values were typically small (< 2.5 $ml \cdot kg^{-1} \cdot min^{-1}$) and non-significant ($p > 0.05$) for each predictive model (Table 4.3). Interestingly, the $RPE_{19}$ model generated the smallest

biases in trials 1 and 2, whereas the $RPE_{20}$ model generated the smallest bias in trial 3 (0.6 $ml \cdot kg^{-1} \cdot min^{-1}$). Importantly, the 95% LoA between the PRET predictions and the criterion measure were narrowest in trial 3 when $RPE_{20}$ was used (Table 4.4 & Figure 4.1). Expressed as a 'margin of error', this degree of variation equates to approximately ±15%. Moreover, this reflects a marked improvement from the first trial in which the error was approximately 27%.

**Table 4.1** Mean (± SD) oxygen uptake values ($ml \cdot kg^{-1} \cdot min^{-1}$) across three PRET trials.

| RPE level | Trial 1 | | Trial 2 | | Trial 3 | |
|---|---|---|---|---|---|---|
| | $\dot{V}O_2$ | % $\dot{V}O_2$max | $\dot{V}O_2$ | % $\dot{V}O_2$max | $\dot{V}O_2$ | % $\dot{V}O_2$max |
| **9** | 16.6 ± 4.8 | 33.2 | 14.9 ± 3.8 | 30.3 | 15.6 ± 4.8 | 32.9 |
| **11** | 21.2 ± 6.0 | 42.4 | 18.5 ± 5.3 | 37.6 | 19.2 ± 6.3 | 40.5 |
| **13** | 28.5 ± 6.2 | 57.0 | 27.1 ± 5.8 | 55.1 | 24.5 ± 7.2 | 51.7 |
| **15** | 36.3 ± 6.4 | 72.6 | 35.1 ± 5.5 | 71.4 | 34.7 ± 5.6 | 73.3 |

**Table 4.2** Mean (± SD) heart rate ($beats \cdot min^{-1}$) across three PRET trials

| RPE level | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| **9** | 111 ± 14.0 | 107 ± 15.7 | 107 ± 16.7 |
| **11** | 125 ± 18.1 | 119 ± 19.2 | 118 ± 19.7 |
| **13** | 150 ± 19.2 | 142 ± 21.0 | 137 ± 22.9 |
| **15** | 173 ± 17.8 | 168 ± 18.1 | 166 ± 18.9 |

**Table 4.3** Mean (± SD) predicted oxygen uptake values ($ml \cdot kg^{-1} \cdot min^{-1}$) across three PRETs.

| RPE* | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| **$RPE_{20}$** | 49.9 ± 10.1 | 49.0 ± 8.1 | 47.4 ± 6.9 |
| **$RPE_{19}$** | 48.8 ± 10.8 | 48.2 ± 8.6 | 45.5 ± 7.8 |

*Highest value used in $\dot{V}O_2max$ regression analysis.

**Table 4.4** Agreement[1] of PRET predicted and actual $\dot{V}O_2max$ values.

| | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| **$RPE_{20}$** | 1.9 ± 13.3 | 1.0 ± 8.8 | -0.6 ± 7.1 |
| **$RPE_{19}$** | 0.8 ± 16.4 | 0.2 ± 10.3 | -2.5 ± 9.4 |

[1]LoA ($ml \cdot kg^{-1} \cdot min^{-1}$)

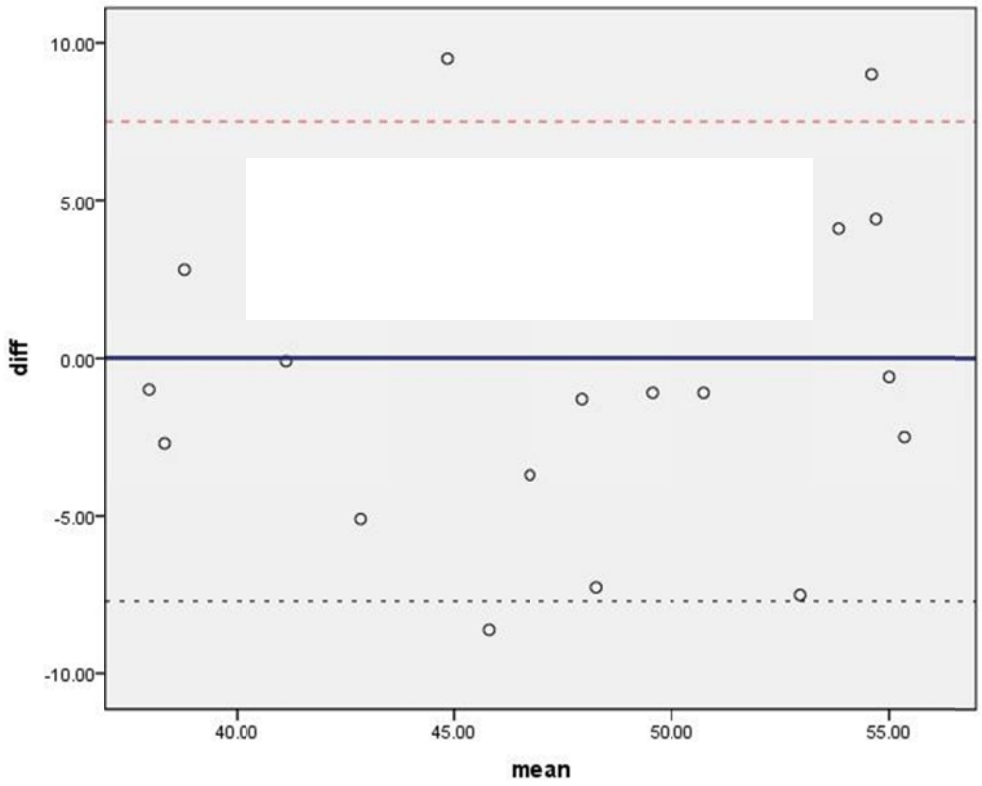


**Figure 4.1** Bland –Altman plot demonstrating the optimal LoAs for RPE 20 trial 3

The statistics in Table 4.5 show the reproducibility of predicted $\dot{V}O_2$max calculated via each model over three trials. Two key findings are evident; firstly, for both models the LoA are narrower (indicating better agreement) between trials 2 and 3 than between the first two trials, and secondly, the consistency of the $RPE_{20}$ predictions is superior to those generated by the $RPE_{19}$ model.

**Table 4.5** Reliability of $\dot{V}O_2$max predictions across repeated trials.

| Trial | Predictive Model | | | | | |
|---|---|---|---|---|---|---|
| | $RPE_{20}$ | | | $RPE_{19}$ | | |
| | **ICC** | **95% LoA[1]** | **Typical Error[1]** | **ICC** | **95% LoA[1]** | **Typical Error[1]** |
| **T1 – T2** | 0.76 | 0.9 ± 12.3 | ± 4.4 | 0.73 | 0.6 ± 14.4 | ± 5.2 |
| **T2 – T3** | 0.84 | 1.6 ± 8.5 | ± 3.1 | 0.79 | 2.7 ± 9.4 | ± 3.4 |

[1]$ml \cdot kg^{-1} \cdot min^{-1}$

## 4.5 Discussion

The current investigation has provided data which are commensurate with those of several recent studies dealing with the validity of predicting $\dot{V}O_2$max via a perceptually regulated exercise test (Eston *et al.,* 2005; 2006; Faulkner *et al.,* 2006; Study 1 of this thesis). These findings have an advantage over previous studies in that they were produced on a treadmill and from a protocol that had an upper limit of RPE 15. In particular, this treadmill-based PRET generated relatively accurate predictions for most participants despite the perceptual range being confined to RPE 9-15. Furthermore, and in keeping with previous studies, the reproducibility of these predictions was seen to improve with practice to a level that could facilitate their application in exercise interventions.

That the current active participants, individually and as a sample, were generally able to adjust their exercise output from a low (RPE 9; approx. 32% $\dot{V}O_2$max) to a recommended safe and effective level (RPE 15; approx. 72% $\dot{V}$

$O_2$max) was not an unexpected finding given the incremental and continuous nature of the PRETs employed. Previous studies have demonstrated this competency during incremental cycling (Faulkner *et al.,* 2007; Eston *et al.,* 2006; 2008), among both active and sedentary individuals, albeit involving protocols that extended exercise effort to a level of RPE 17 which for many participants might be >80% $\dot{V}O_2$max and inappropriate (ACSM, 2010; AACVPR, 2006; BACR, 1995). More impressive was the accuracy of the $\dot{V}O_2$max predictions, given that oxygen uptake data were gathered from only four stages (9, 11, 13 and 15). The optimum level of agreement between predicted and measured $\dot{V}O_2$max (-0.6 ± 7.1 $ml \cdot kg^{-1} \cdot min^{-1}$, or ± 15%) is almost identical to that observed in Study 1, that used a cycling-based PRET across the range 9-17 (± 17%) and compares favourably to the findings from previously reported truncated (9-15) prediction models (up to $RPE_{20}$). That is, the random (within-subjects) error being ± 8.4 (± 23%; Eston *et al.,* 2005), ± 12.4 (31%; Eston *et al.,* 2008), ± 11.2 (26%; Faulkner *et al.,* 2007), ± 10.6 (22%; Eston *et al.,* 2006) and ± 10.8 (26%; observed in Study 1) $ml \cdot kg^{-1} \cdot min^{-1}$. This lower margin of error revealed in the current study supports the notion that a PRET devoid of a "Very hard" (RPE 17) stage would benefit a participant's compliance with the task and reduce the likelihood of his/her adopting a pacing strategy (Tucker, 2009).

The accuracy of the $\dot{V}O_2$max predictions was improved after the first of the three PRETs, and likewise after the second, reinforcing the merit of habituating participants to the task of governing their own exercise intensity in this way. This

finding was independent of which prediction model was used, but after three trials, the $RPE_{20}$ model proved to be most accurate. Based on their truncated (9-15) models, Faulkner *et al.* (2007) reported not much difference between the $RPE_{20}$ and $RPE_{19}$ predictions, although based on the full range (9-17) the $RPE_{19}$ model was more accurate (after three trials).

In absolute terms, the interpretation of the agreement between the current predicted and actual measures of $\dot{V}O_2$max warrants attention, particularly as this has tended to be overlooked in previous investigations. In the manner exemplified in Study 1, the best LoA from the current data infer that, in the worst case, an individual with a $\dot{V}O_2$max of say, 40 $ml \cdot kg^{-1} \cdot min^{-1}$, could have a predicted value of as high as 47 or as low as 33 $ml \cdot kg^{-1} \cdot min^{-1}$. Whilst comparable figures for other indirect methods of predicting maximal oxygen uptake are scarce, they compare well to those reported for the established Astrand cycle test (Nevill & Atkinson, 1997) and the Chester step test (Buckley *et al.,* 2004), both of which are reliant on measures of heart rates. Moreover, 15 (84%) of the participants had PRET predicted values (from trial 3) that were within ± 5.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (± 11.5%) of their actual $\dot{V}O_2$max. Given that a small proportion of adults can be expected to have difficulties in understanding and utilising the RPE scale (Borg, 1998), this lower figure is probably more realistic and, depending on the goals of the individual or exercise practitioner (or clinician), deserves a favourable interpretation.

The consistency of the $\dot{V}O_2$max predictions from the two models improved markedly after the first trial, and was optimum between trials 2 and 3 for the $RPE_{20}$ model. Whilst slightly less impressive than the equivalent statistics reported in Study 1 for cycle ergometry (0.7. ± 7.3 $ml \cdot kg^{-1} min^{-1}$), this level of agreement sits well alongside those reported in a positive manner for truncated 9-15 ranges (also for cycle ergometry) by Faulkner *et al.* (2007; -0.6 ± 12.0 $ml \cdot kg^{-1} min^{-1}$) and Eston *et al.* (2007; 1.3 ± 9.7 $ml \cdot kg^{-1} \cdot min^{-1}$). In addition, this could be due to the absence of the relatively high RPE 17 stage from the current study and its negative impact on the validity of the participants' task compliance. Notwithstanding this, the reliability of the predicted $\dot{V}O_2$max values reflects agreement for 95% of the sample that at worst is ± 8.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (± 17.5%) and for those 15 participants whose predictions were most accurate (see above), their reliability was, not surprisingly, better at ± 6.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (± 13.5%). Moreover, if the somewhat liberal 'typical error' calculation of reliability is adopted, the interpretation is better still because the agreement between trials is about one third of the LoA. However, the optimal typical error for the current data (3.1 $ml \cdot kg^{-1} min^{-1}$) only reflects the reliability for about two-thirds of our sample, and not most (95%) as reflected in the limits of agreement.

The matter of whether such agreement, as with the analysis of validity, is 'acceptable' or not has typically received inadequate attention in research of this kind as stated in Study 1. One useful approach in dealing with this is to consider whether the extent of the trial-to-trial reliability observed would mask any 'real'

variability (change) in $\dot{V}O_2$max that might be expected to occur due to an intervention or training programme? Previously in Study 1 it was argued that changes in excess of the magnitude of those reported (between 3.1 and 8.5 ml·kg$^{-1}$·min$^{-1}$ in this study, depending on the reliability statistic used) would be necessary. Therefore, since such changes are likely to occur among healthy populations following suitable training the reliability of the current predictions can be evaluated optimistically.

In conclusion, the validity of a treadmill-based sub-maximal PRET as a predictor of $\dot{V}O_2$max has been found to be comparable to that reported previously in studies utilising a cycle-based PRET. This is notable given that the protocol did not extend participants beyond RPE 15 ("Hard") and is more realistic for individuals for whom intense exercise is not recommended. It is evident that, given practice, such a protocol can yield predictions of $\dot{V}O_2$max that have satisfactory reliability and are more accurate than other heart rate-related predictive methods. These findings augur well for future investigations into the application of PRETs with different modes of exercise and in environments where maximal tests are contra-indicated owing to poor health or fitness status or the use of drug interventions, such as β-blocker therapy.

# Chapter 5

# Study 3

The efficacy of predicting maximal oxygen uptake from a shortened perceptually regulated exercise test (PRET)

Aspects of this chapter were presented at the European College of Sports Science (ECSS) Annual Congress (Oslo, 2009).

## 5.1 Abstract

The purpose of this study was to assess whether maximal aerobic capacity ($\dot{V}O_2max$) could be predicted with acceptable accuracy and reliability from oxygen uptake ($\dot{V}O_2$) values produced during a sub-maximal perceptually-regulated exercise test (PRET) with a ceiling intensity of RPE 15. This modification of previously trialled PRETs may provide a safer and potentially more appropriate protocol for sedentary individuals and clinical populations. Sixteen healthy volunteers (27.5 ± 7.9 years) completed three PRETs (separated by 48-72 h) and one maximal graded exercise test on a magnetically braked cycle ergometer. Participants self-regulated the exercise intensity at RPE levels 9, 11, 13 and 15 in a discontinuous and randomised manner. $\dot{V}O_2$ was recorded continuously during each 3 min exercise bout and individual values for the RPE range (9-15) were extrapolated to RPE 19 and 20 using regression analysis to predict a $\dot{V}O_2max$ score. Data analysis revealed optimal limits of agreement (LoA) for the prediction model to RPE 20 between actual (40.3 ± 6.8 $ml \cdot kg^{-1} \cdot min^{-1}$) and predicted scores (35.8 ± 6.8 $ml \cdot kg^{-1} \cdot min^{-1}$) which were -4.51 ± 11.8 $ml \cdot kg^{-1} \cdot min^{-1}$. The reproducibility of the $\dot{V}O_2max$ predictions improved from trial-to-trial and at best equated to LoA of -0.81 ± 7.6 $ml \cdot kg^{-1} \cdot min^{-1}$ and typical error of 2.8 $ml \cdot kg^{-1} \cdot min^{-1}$. These findings highlight that a shortened PRET protocol can produce predictions of $\dot{V}O_2max$ that are comparable in validity to those generated via longer protocols and as reliable. Accordingly, there is scope to apply this protocol in a setting in which exercise tolerance is limited in terms of functional capacity and health risk.

## 5.2 Introduction

Borg's (1998) 6–20 rating of perceived exertion (RPE) scale is a well-established tool that is commonly used for quantifying the intensity of exercise and for prescribing exercise in healthy adults and some special populations (ACSM, 2010; Bird & Davidson, 1997). It is most often used as a response measurement (termed *estimation mode*) during graded exercise tests whereby the exerciser is presented with the scale and at a particular moment asked to select a rating that reflects how hard the exercise feels. An alternative use of the scale (although less popular) involves the exerciser self-adjusting the intensity or producing an exercise intensity (termed *production mode*) that is prescribed to them as fixed RPE levels (e.g. 9, 11, 13 or 15). A large body of evidence has confirmed the reliability and validity of the 6-20 scale in a variety of exercise modalities in both estimation (Carton & Rhodes, 1985; Chen, Fan, & Moe, 2002; Groslambert & Mahon, 2006) and production modes (Eston *et al.*, 1987; Ceci & Hassmen, 1992; Green & Solomon, 1999; Hartshorn & Lamb, 2004; Goosey-Tolfrey *et al.*, 2010).

It was with this in mind that a development emerged in 2005 whereby the efficacy of predicting maximal oxygen uptake ($\dot{V}O_2max$) from a sub-maximal perceptually-regulated exercise test (PRET) was explored (Eston *et al.*, 2005). This novel application has advantages over other predictive methods that utilise heart rate, as it is not susceptible to errors in the prediction of maximal heart rate (up to ± 20 beats·min$^{-1}$) that can be expected (Londeree & Moeschberger, 1984; Buckley *et al.*, 1984). In addition, medications (e.g. beta-blockers) and environmental

conditions (e.g. heat) have been shown to have little effect on perceived exertion (Kang *et al.*, 1998; Eston & Connolly, 1996), as they do heart rate. The first study by Eston *et al.* (2005) among young, active males predicted $\dot{V}O_2$max from an incremental cycle PRET at RPE levels 9, 11, 13, 15 and 17 to within ± 6 $ml \cdot kg^{-1} \cdot min^{-1}$ of the criterion values. A subsequent study addressed the predictive success of the cycle PRET when different lengths of exercise bouts were employed (Eston *et al.*, 2006). The same five self-regulated intensities were employed as in the original study but this time each of the increments were maintained for either two or four minutes. It was suggested that the two-minute bout was superior due to the lower limits of agreement achieved (-0.47 ± 7.44 $ml \cdot kg^{-1} \cdot min^{-1}$), with the mean value being closer to actual $\dot{V}O_2$max by <1.0 $ml \cdot kg^{-1} \cdot min^{-1}$. A further study investigated the PRET among active versus sedentary male and female populations (Faulkner *et al.*, 2007), again employing a similar research design. When the RPE ranges were extrapolated to RPE 20 $\dot{V}O_2$max was significantly overestimated ($p$ < 0.05), although there was no difference when extrapolated to RPE 19. The prediction of $\dot{V}O_2$max was also not moderated by gender or activity status, although the LoA were slightly wider than previous studies had reported (0.4 ± 8.4 $ml \cdot kg^{-1} \cdot min^{-1}$). Again practice improved the prediction especially in the sedentary group as they experienced a significantly greater proportional increase in work rate at the moderate RPE levels (11, 13 and 15) between the first and final PRET trials. This study also compared the PRET against age predicted max heart rate and demonstrated that the PRET was at least as good a predictor, if not better. Similar findings have been observed in middle-

aged sedentary males this time during a discontinuous PRET protocol, although again the LoA are slightly wider (3.7 ± 12.8 $ml \cdot kg^{-1} \cdot min^{-1}$) than the original two investigations (Eston, *et al.*, 2007). A common theme in these studies was that the PRETs were predicted from a wide range of RPEs up to a maximum of RPE 17 (Very hard), a level that could be considered too strenuous for sedentary or clinical populations (ACSM, 2010; BACR, 1995). On reflection, authors in these studies acknowledged this and provided estimations from truncated RPE ranges (typically 9-15 or 9-13) which produced predictions that were noticeably wider than the 9-17 predictions and were possibly excessive. It was quite possible that the inclusion of RPE 17 in the PRET protocol could have affected the regulation at the lower levels as participants may be likely to under regulate their exercise as part of a pacing strategy as suggested by Faulkner *et al.* (2007). Study 2 of this thesis was the first to have a ceiling intensity of RPE 15, albeit during treadmill exercise, and therefore the purpose of this study was to assess the criterion validity of a cycle PRET protocol with a maximum intensity of RPE 15 and assess the reliability of the predictions over three repeated trials.

## 5.3 Method

### 5.3.1 Participants

Sixteen (seven males and nine females) healthy active participants (27.5 ± 7.9 years, 67.2 ± 10.98 kg, 167 ± 6.6 cm) were recruited from a University population and local health club (Appendix 3). After receiving oral and written information on the study (Appendix 9), all volunteers gave their consent (Appendix 11) to participate and prior to each testing session completed a pre-test health

status questionnaire (Appendix 6). Ethical approval was granted by the Faculty of Applied Sciences Research Ethics Committee at the University of Chester (Appendix 4).

### 5.3.2 Procedures

A repeated measures design was utilised which required participants to attend the laboratory on four separate occasions (48-72 h apart), three times to perform a discontinuous, sub-maximal PRET and one further time to perform a graded exercise test (GXT) to exhaustion ($\dot{V}O_2$max). The PRETs were administered on three occasions as previous studies have demonstrated how practice informs the accuracy and reliability of the $\dot{V}O_2$max predictions (Eston *et al.*, 2005; 2006; Faulkner *et al.,* 2007). The $\dot{V}O_2$max test was performed following the three PRETs as this would have provided an 'exercise anchoring' session, exposing participants to the full perceptual range, something which would not be afforded to participants outside a laboratory setting and in circumstances for which sub-maximal tests might be particularly useful (e.g. special populations or sedentary). All exercise was conducted on an electronically braked cycle ergometer (Lode Corival; Lode BV, Groningen, The Netherlands) at a cadence maintained between 50-80 revs·min$^{-1}$. All the data on the cycle's display (e.g. power output and heart rate) was concealed from participants at all times in order not to provide feedback other than their perceived exertion. Oxygen uptake was measured continuously during each exercise session via breath-by-breath online gas analysis (Oxycon; Jaeger Erich GmbH. Höchberg, Germany) and a Polar

wireless chest strap (Polar Electro Oy, Kempele, Finland) linked to the gas analyser. Gas and volume calibrations were performed before each testing session in accordance with the manufacturer's guidelines. Each participant was tested at a similar time of day as their previous session/s (within ± 2 h) to control for physiological variation caused by circadian rhythms (Reilly, 2007; Zwierska *et al.*, 2001; 2000). Participants were asked to refrain from vigorous exercise (48hrs), alcohol (48hrs), tobacco (3hrs) and caffeine (12hrs) before each testing session.

### 5.3.3 Sub-maximal perceptually-regulated exercise test (PRET)

Prior to performing each PRET participants were presented with a large cardboard format of the Borg 6-20 RPE scale (Borg, 1998) and read out a set of instructions (see Study 1) specific to *regulating* exercise intensity with the scale. Following this, each PRET protocol required participants to regulate their intensity to match four RPE levels (9 – Very light, 11 – Light, 13 – Somewhat hard and 15 – Hard (heavy) which were presented by the investigator in a randomised order. Participants first completed a warm-up for five minutes between 50–100 Watts (depending on the fitness of the participant) followed by a five minute rest. With no resistance on the cycle participants were then instructed to reach the required cadence (50–80 revs·min$^{-1}$) and then instruct the investigator to adjust the intensity on the control panel equivalent to the initial effort rating. Participants were given up to three minutes to adjust the exercise intensity to their satisfaction (which matched the prescribed level), at which time their expired air was recorded for three minutes. One minute into the recording participants were afforded a further opportunity for adjustment of the self-regulated intensity. At the end of the bout the

resistance was removed and the participants instructed to continue pedalling slowly for three minutes. This procedure was then repeated for the other three RPE levels. The mean oxygen uptake and heart rate during the final 30 s of each RPE level in all bouts were calculated. Upon completion a cool-down was performed at 40 W until heart rate dropped below 100 $b \cdot min^{-1}$.

### 5.3.4 Graded exercise test (GXT)

The GXT ($\dot{V}O_2max$) protocol required participants to perform a light 5-minute warm-up (on the same cycle ergometer used during the PRET trials), followed by an incremental continuous protocol starting at 50 W and increasing by 40 W every 3 minutes until volitional exhaustion. Expired air, HR and RPE were measured throughout with blood lactate being measured following the cessation of exercise (Lactate Pro, Arkray Japan). The establishment of achieving $\dot{V}O_2max$ for each participant was evaluated against the criteria set out by Bird and Davidson (1997) on behalf of the British Association of Sport and Exercise Sciences - volitional exhaustion, a plateau in $VO_2$, RPE 19 or 20, HR within ± 10 beats of age-predicted maximum, post-exercise lactate >8 $mmol \cdot l^{-1}$ and a respiratory exchange ratio >1.15 – and confirmed if four of them were met. In acknowledging the research by Poole *et al.* (2008) which suggests that using these criteria may underestimate $\dot{V}O_2max$ by up to 27%, at no point were participants instructed to cease exercise when these criteria were achieved. Moreover, they were verbally encouraged to produce a maximal effort and only at volitional exhaustion was the test terminated. Thereafter, the secondary criteria were inspected.

### 5.3.5 Data analysis

Descriptive statistics (mean ± SD) were calculated following confirmation of normal distribution via the Shapiro-Wilk statistic for $\dot{V}O_2$ across all four exercise trials at each RPE level. In the manner of previous research in this area (Eston *et al.*, 2005; 2006; 2008; Faulkner *et al.,* 2007) individual linear regression analyses ( $\dot{V}O_2$ = a + b x RPE) were performed on each participant's four measured $\dot{V}O_2$ values (from RPE levels 9, 11, 13 and 15) to predict their GXT determined $\dot{V}O_2$max at the theoretical RPE 20 end-point. Additionally, a regression model was developed with RPE 19 as the end-point as this is often the value reported in GXTs (Eston *et al*., 2012). Separate one way ANOVAs were utilised for each predictive model to compare trial means to actual $\dot{V}O_2$max scores, any differences were followed up with Bonferroni adjusted paired *t*-tests. The agreement between the criterion $\dot{V}O_2$max values and those predicted from the PRETs were calculated with the 95% limits of agreement (LoA) technique, on the basis that the errors (differences) were found to be normally distributed and homoscedastic (Bland & Altman, 1986).The LoA (bias ± 1.96 x $SD_{diff}$) technique was also used to assess the reproducibility of the $\dot{V}O_2$max predictions across the three PRET trials, with the addition of the typical error ($SD_{diff}$ /√2; Hopkins, 2000) and the intraclass correlation coefficient (ICC), calculated via a two-way mixed effects model for absolute agreement. All data analyses were conducted using SPSS for Windows (version 18.0) and alpha was set at the 0.05 level.

### 5.4 Results

All participants satisfied the requisite criteria for achieving $\dot{V}O_2$max during the GXT and the mean value was 40.3 ± 6.8 $ml \cdot kg^{-1} \cdot min^{-1}$. In each PRET trial, increases in RPE level were accompanied by significant increases in mean $\dot{V}O_2$ ($F = 157.21$, $df = 1.6$, $p < 0.0005$; Table 5.1), HR ($F = 0.33$, $df = 1.7$, $p = 0.72$; Table 5.2) and power output ($F = 272.27$, $df = 1.4$, $p < 0.0005$; Table 5.3). Neither the effect of trial on $\dot{V}O_2$ ($F = 0.08$, $df = 1.8$, $p = 0.92$), HR ($F = 0.33$, $df = 2.0$, $p = 0.72$) or power output ($F = 0.11$, $df = 2.0$, $p = 0.89$) was significant, nor was the trial x RPE level interaction ($F = 1.09$, $df = 3.5$, $p = 0.37$; $F = 2.3$, $df = 3.9$, $p = 0.07$; $F = 0.58$, $df = 3.0$, $p = 0.62$), reflecting consistency in the intensity of the PRETs. All the individual RPE-$\dot{V}O_2$ correlations exceeded 0.90, except for one participant whose coefficient was consistently 0.88 across the trials. By the third trial, 80% of participants' correlations were 0.98 or above. The mean differences between measured $\dot{V}O_2$max and those predicted from the PRET were relatively small (< -4.6 $ml \cdot kg^{-1} \cdot min^{-1}$) and non-significant ($F = 3.4$, $p = 0.06$), with the smallest observed in trial 1 (-2.4 $ml \cdot kg^{-1} \cdot min^{-1}$). However, the PRET predictions were most accurate in trial 3, as borne out by the lower LoA statistics (Table 5.4 & Figure 5.1).

The reproducibility of the PRETs across the three trials (presented in Table 5.5) can be seen to be superior between trials 2 and 3, with the narrowest LoA (indicating better agreement), typical error, and highest ICCs.

**Table 5.1** Mean (± SD) oxygen uptake values ($ml \cdot kg^{-1} \cdot min^{-1}$) across three PRET trials.

| RPE level | Trial 1 | | Trial 2 | | Trial 3 | |
|---|---|---|---|---|---|---|
| | $\dot{V}O_2$ | % $\dot{V}O_2$max | $\dot{V}O_2$ | % $\dot{V}O_2$max | $\dot{V}O_2$ | % $\dot{V}O_2$max |
| **9** | 11.3 ± 2.6 | 28.0 ± 6.4 | 11.9 ± 2.9 | 29.5 ± 7.3 | 12.1 ± 2.5 | 30.1 ± 6.3 |
| **11** | 15.3 ± 3.1 | 37.9 ± 7.8 | 15.6 ± 2.7 | 38.9 ± 6.8 | 15.1 ± 2.6 | 37.4 ± 6.5 |
| **13** | 21.3 ± 4.4 | 2.7 ± 11.0 | 20.6 ± 3.7 | 51.0 ± 9.2 | 20.5 ± 3.5 | 50.9 ± 8.8 |
| **15** | 25.6 ± 4.8 | 63.4 ± 11.8 | 24.8 ± 4.7 | 61.4 ± 1.7 | 24.8 ± 3.8 | 61.5 ± 9.3 |
| **Criterion $VO_2$max** | 40.3 ± 6.8 | | | | | |
| **Prediction to RPE 19** | 35.5 ± 7.7 | | 33.5 ± 6.8 | | 33.4 ± 6.2 | |
| **Prediction to RPE 20** | 38.0 ± 8.5 | | 35.6 ± 7.4 | | 35.8 ± 6.8 | |

**Table 5.2** Mean (± SD) heart rate ($beats \cdot min^{-1}$) across three PRET trials.

| RPE level | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| **9** | 99 ± 15.7 | 102 ± 15.9 | 106 ± 16.9 |
| **11** | 116 ± 14.8 | 113 ± 12.9 | 117 ± 14.8 |
| **13** | 134 ± 21.7 | 134 ± 19.1 | 132 ± 17.6 |
| **15** | 147 ± 20.9 | 147 ± 17.8 | 148 ± 18.6 |

**Table 5.3** Mean (± SD) power output (W) across two PRET trials.

| RPE level | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| **9** | 31 ± 12.0 | 33 ± 12.6 | 36 ± 12.0 |
| **11** | 58 ± 16.2 | 59 ± 17.0 | 60 ± 13.8 |
| **13** | 92 ± 24.0 | 91 ± 18.2 | 90 ± 17.6 |
| **15** | 116 ± 26.2 | 117 ± 26.7 | 116 ± 21.5 |

**Table 5.4** Agreement* (expressed as $ml \cdot kg^{-1} \cdot min^{-1}$) of PRET predicted and actual $\dot{V}O_2max$ values.

| Prediction model | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| **$RPE_{19}$** | -4.9 ± 17.8 | -6.8 ± 14.6 | -7.0 ± 11.9 |
| **$RPE_{20}$** | -2.4 ± 18.9 | -4.6 ± 15.3 | -4.5 ± 11.8 |

* 95% limits of agreement

**Table 5.5** Reliability of $\dot{V}O_2max$ predictions across repeated trials.

| Prediction model | Trial | ICC | 95% LoA[1] | Typical error[1] |
|---|---|---|---|---|
| **$RPE_{19}$** | **T1 – T2** | 0.81 | 2.0 ± 9.3 | ± 3.4 |
| | **T2 – T3** | 0.89 | 0.1 ± 6.4 | ± 2.3 |
| **$RPE_{20}$** | **T1 – T2** | 0.81 | 2.3 ± 10.2 | ± 3.7 |
| | **T2 – T3** | 0.87 | -0.8 ± 7.6 | ± 2.8 |

[1] $ml \cdot kg^{-1} \cdot min^{-1}$

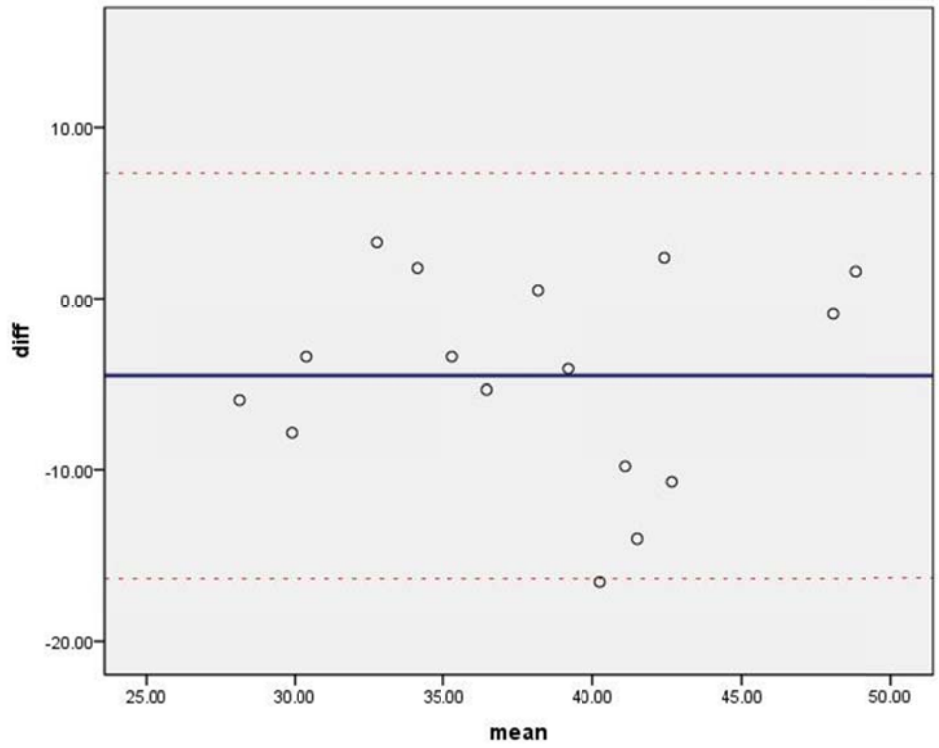


**Figure 5.1** Bland-Altman plot demonstrating the optimal LoAs for RPE 9-15 RPE 20 trial 3.

### 5.5 Discussion

It is evident from the above data, and in keeping with a substantial body of previous literature, the participants in this study were able to regulate successfully (and reliably over repeated trials) their exercise effort on the basis of their perceptions of effort. Objective markers of effort ($\dot{V}O_2$ and HR) varied proportionally with changing RPE levels and were consistent across three trials. More specifically though, the shortened cycle PRET utilised in this study provided optimal estimates of $\dot{V}O_2$max within -4.5 ± 11.8 ml·kg$^{-1}$·min$^{-1}$, which are higher than those reported in the original study by Eston *et al.* (2005) and some subsequent investigations (Eston *et al.*, 2006; Faulkner *et al.,* 2007), although commensurate

with Eston *et al.* (2007). However, it should be noted that the predictions from these earlier studies included an intensity of RPE 17, which might be considered too high for sedentary and clinical populations, whereas the current study is the first to employ a cycle PRET with a ceiling intensity of RPE 15. It is apparent though that the 'cost' of such an adaptation was the removal of an exercise intensity (RPE 17) that typically provides strong perceptual feedback to participants and a subsequent loss of predictive accuracy. Indeed, when the aforementioned PRET studies truncated their RPE prediction models to RPE 9-15, the agreement between the predicted and criterion $\dot{V}O_2$max values became wider (worse) than for the full (9-17) model, and inferior to this study's findings. This adds credence to the suspicion that the inclusion of the "Very hard" RPE level (RPE 17) in such a PRET has a bearing on the exerciser's regulation of effort at the three lower intensity levels (9, 11, 13, and 15). As previously mentioned, the work of Faulkner *et al.* (2007) suggests participants are likely to under-regulate the exercise intensity as part of a pacing strategy as they are aware of what maximum RPE is expected of them, consequently altering the previous RPE levels.

In the first study to adopt a ceiling intensity of RPE 15 (Study 2) optimal LoAs (in trial 3) of -0.6 ± 7.1 $ml \cdot kg^{-1} \cdot min^{-1}$ were observed during treadmill exercise among the sample of active young adults. Whilst this study (Study 2) produced narrower (better) LoA than the results presented here, it is noteworthy that a continuous incremental protocol was used. It is possible that an incremental protocol is easier for participants to regulate than a discontinuous, randomised

protocol as they will be able to use the sensations they have experienced of the prior RPE level and know they simply need to add more resistance during an incremental protocol. Moreover, it has also been postulated that walking and running are more familiar and habitual modes of exercise than stationary cycling for the average individual (Eston *et al.*, 2012), which could account for the stronger concordance between the predicted and actual $\dot{V}O_2$max values in Study 2. Interestingly, a recently published study has also adopted the approach first advocated in Study 2 of using a shortened treadmill-based PRET (up to RPE 15) and has produced comparable results (Eston *et al.*, 2012). That is, among their active, young adults, $\dot{V}O_2$max predictions from a 9-15 protocol were (optimally) within 0.4 ± 8.3 ml·kg$^{-1}$·min$^{-1}$ of measured values, and were interpreted favourably as being a valid means of predicting $\dot{V}O_2$peak. In the same study, equivalent statistics for a separate group of sedentary adults were less impressively, 0.2 ± 11.0 ml·kg$^{-1}$·min$^{-1}$. This might be explained by the fact the sedentary participants' percentage of $\dot{V}O_2$peak at each RPE level was lower ($p$ < 0.01) than the young active participants. It was postulated that this might have been owing to a lower perceived tolerance for a given intensity, borne out of a lack of experience and habituation to the exercise protocol, and the understandable adoption of a more conservative approach. Alternatively, a more likely explanation was their lower ventilatory thresholds, which occur at a low proportion of $\dot{V}O_2$peak in the absence of training (Hill *et al.,* 1987; Eston *et al.,* 2012).

Eston *et al.* (2012) also observed that the prediction to RPE 19 (rather than RPE 20) produced better agreement; a phenomenon that has been reported elsewhere (Faulkner *et al.*, 2007), but not in Study 2 of this thesis. The current study shows, as with others (Eston *et al.*, 2006; Studies 1 and 2) that the PRET generally under-predicts $\dot{V}O_2$max. Although Eston *et al.* (2012) did report that when using the truncated RPE range 9–13, $\dot{V}O_2$peak was significantly ($p < 0.05$) under-predicted for their sedentary participants when extrapolated to RPE 19. This suggests that in instances where intensities above RPE 13 are undesirable, a prediction to RPE 20 is advocated to provide a more accurate prediction of $\dot{V}O_2$peak. Further research is necessary to resolve whether RPE 19 or 20 is the most appropriate prediction model, and to what extent this issue is population-dependent. However, the relative intensity at RPE 13 produced a range of 42-60% $\dot{V}O_2$max, which although was slightly lower than in previous work (55-66% $\dot{V}O_2$max, Faulkner *et al.*, 2007) was still within the suggested guidelines for exercise prescription (ACSM, 2010) and therefore appropriate for regulating exercise intensity in rehabilitation and training programmes.

As observed in all previous investigations of this kind the accuracy of the $\dot{V}O_2$max predictions improved after the first trial, and again following the second trial, which supports the use of habituating participants to the task of regulating their own intensity in this way. In Study 2 such a change was also observed with an RPE range of 9–15 during treadmill exercise and most recently Eston *et al.* (2012) demonstrated a similar pattern. However, it is not known if a further trial would have improved the accuracy of the prediction more; no study to-date has

conducted more than three trials of the same PRET procedure. The consistency of the predictions also improved markedly following the first trial, and was best between trials 2 and 3 (-0.8 ± 7.6 $ml \cdot kg^{-1} \cdot min^{-1}$). This sits favourably alongside previous investigations which have included an intensity of RPE 17 (Study 1) and also with those using a truncated RPE range of 9- 15 (Faulkner *et al.,* 2007; -0.6 ± 12.0 $ml \cdot kg^{-1} min^{-1}$; Eston *et al.,* 2007; 1.3 ± 9.7 $ml \cdot kg^{-1} \cdot min^{-1}$). Interestingly, the most recent paper by Eston *et al.* (2012) only reported the intraclass correlation as a measure of reliability between their two trials, but demonstrated better repeatability among the sedentary participants (0.94) than their active counterparts (0.76). This was attributed to the sedentary participants adapting well to the treadmill task and not over-estimating their effort, along with the mode of exercise being more familiar to them. Clearly, the variety of statistical techniques used to investigate reliability amongst researchers is a concern, as some can be said to enable a more favourable interpretation of their results. It may be useful for researchers to consider using a variety of statistical techniques to provide a full appraisal of their results, which would also allow comparisons to be made between studies.

In conclusion, the validity of the cycle PRET with a ceiling intensity of RPE 15 has been found to be comparable to studies that have utilised a more strenuous PRET. This could have practical implications in certain exercise settings, such as those that involve sedentary or clinical populations. The PRET protocol is an appropriate method to adopt when maximal exercise testing is not appropriate or where heart rate does not provide a trustworthy measure of objective effort. Further

investigations are warranted with a shortened, continuous cycle PRET among clinical populations.

# Chapter 6

# Study 4

The prediction of peak oxygen uptake from a sub-maximal perceptually-regulated exercise test (PRET) in heart failure patients

## 6.1 Abstract

The purpose of this study was to assess whether peak oxygen uptake ($\dot{V}O_2$peak) could be predicted with acceptable accuracy and reliability from a sub-maximal PRET with a ceiling intensity of RPE 15 in patients with heart failure. Previous investigations have successfully demonstrated the PRET to be as accurate as predictive heart rate methods in healthy individuals, but to-date no research exists in clinical populations. Sixteen beta-blocked heart failure patients (70.4 ± 7.0 y) completed one maximal GXT and two PRETs (separated by 48-72 h) on a magnetically braked cycle ergometer. Participants self-regulated the exercise intensity at RPE levels 9, 11, 13 and 15 in a continuous, incremental protocol. Oxygen uptake ($\dot{V}O_2$) was recorded continuously during each 2 min exercise bout. $\dot{V}O_2$ values for the RPE range 9-15 were extrapolated to RPE 20 and RPE 19 to predict each individual's recorded $\dot{V}O_2$peak score, along with predictions associated with a truncated RPE range of 9-13. However, as regulating exercise at RPE 15 was problematic, with most patients eliciting unsafe responses (> 75% $\dot{V}O_2$peak), data analysis was centred on the narrower RPE 9-13 range, which yielded favourable limits of agreement (LoA) between actual (mean 16.5 ± 4.9 $ml \cdot kg^{-1} \cdot min^{-1}$) and predicted (mean 16.3 ± 5.1 $ml \cdot kg^{-1} \cdot min^{-1}$) scores of -0.6 ± 5.3 $ml \cdot kg^{-1} \cdot min^{-1}$ for the RPE 19 prediction model. Reliability analysis of the $\dot{V}O_2$ values produced during the PRET provided LoAs of 0.4 ± 6.5 $ml \cdot kg^{-1} \cdot min^{-1}$ and a typical error of 2.4 $ml \cdot kg^{-1} \cdot min^{-1}$. It was concluded that a PRET with a ceiling intensity of RPE 13 provides acceptably valid and reliable predictions of $\dot{V}O_2$peak in heart failure patients.

## 6.2 Introduction

Recent research has provided convincing support for the prediction of maximal oxygen uptake ($\dot{V}O_2max$) via the active production of exercise intensity based on Borg's 6-20 RPE scale in healthy adults (Eston *et al.,* 2005, 2006, 2007, 2012; Faulkner *et al.,* 2007; 2010; Al-Rahamneh & Eston, 2011; Studies 1-3 of this thesis). The original investigation by Eston *et al.* (2005) was based on the premise that a body of research had already confirmed the reliability and validity of RPE to regulate exercise intensity (termed *production mode*) in a number of exercise forms, such as treadmill running (Dunbar *et al.,* 1992; Eston *et al.,* 1987; Glass *et al.,* 1992; Kang *et al.,* 2003), field running (Chow & Wilmore, 1984; Ceci & Hassmen, 1992), cycle ergometry (Kang *et al.,* 1998; Hartshorn & Lamb, 2004; Kang *et al.,* 2009), rowing ergometry (Marriott & Lamb, 1996), arm ergometry (Goosey-Tolfrey *et al.,* 2010), swimming (Green & Solomon, 1999). With this in mind Eston *et al.* (2005) postulated whether the relationship between oxygen uptake ($\dot{V}O_2$) and RPE utilised in production mode could be exploited to predict $\dot{V}O_2max$ during a sub-maximal perceptually-regulated exercise test (PRET).

The first study predicted $\dot{V}O_2max$ from an incremental cycle PRET at RPE levels 9, 11, 13, 15 and 17 (each level lasting four minutes) to within ± 6 $ml \cdot kg^{-1} \cdot min^{-1}$ of actual values in active young males (Eston *et al.,* 2005). A subsequent study addressed the predictive capabilities of the cycle PRET during different lengths (two and four minutes) of exercise bouts (Eston *et al.,* 2006), and it was

concluded that the two-minute bout was superior to the four-minute owing to the better limits of agreement achieved (-0.47 ± 7.44 $ml \cdot kg^{-1} \cdot min^{-1}$), with the mean value being within 1.0 $ml \cdot kg^{-1} \cdot min^{-1}$ of actual $\dot{V}O_2max$. Further studies among active and sedentary male and females (Faulkner, Eston & Parfitt, 2007) and middle-aged sedentary males (Eston, Lambrick, Sheppard & Parfitt, 2007), demonstrated that when the RPE ranges were extrapolated to RPE 20, $\dot{V}O_2max$ was significantly overestimated ($p < 0.05$), although there was no mean difference when extrapolated to RPE 19. In the study by Faulkner *et al.* (2007), the prediction was unaffected by activity status or gender, although the LoA were slightly wider (worse) than those reported previously (0.4 ± 8.4 $ml \cdot kg^{-1} \cdot min^{-1}$). Notably, this study also observed that the prediction of $\dot{V}O_2max$ from the PRET data compared favourably with values predicted from age-predicted maximum heart rates. In the study by Eston *et al.* (2007), which employed a discontinuous PRET, the agreement was worse (3.7 ± 12.8 $ml \cdot kg^{-1} \cdot min^{-1}$) than the original two studies (Eston *et al*., 2005; 2006).

A common practice adopted in these initial investigations was the use of a broad range of RPEs in each PRET, up to a maximum of 17. Such an intensity level ('Very hard') could be considered too demanding and possibly unsafe for sedentary or clinical populations (ACSM, 2010; BACR, 1995). Indeed, this matter was recognised by Eston and colleagues who consequently developed $\dot{V}O_2max$ prediction models from truncated RPE ranges (typically 9-15 or 9-13) which produced agreement values that were noticeably wider than for the full model (9-

17) and somewhat excessive. Arguably, the inclusion of RPE 17 in the PRET protocol might have influenced participants' regulation at the lower RPE levels (9-15). In this scenario it is possible that they under-regulated their exercise output as part of some sort of pacing strategy (Faulkner *et al.,* 2007), knowing they needed to 'leave room' for an RPE 17 bout. Accordingly, the two most recent investigations (involving treadmill exercise) have conducted PRET protocols with a ceiling intensity of RPE 15 ('Hard') and reported $\dot{V}O_2$max estimates with a bias (± 95% LoA) of -0.6 ± 7.1 $ml \cdot kg^{-1} \cdot min^{-1}$ in young, active participants (Study 2 of this thesis), and 0.2 ± 11.0 $ml \cdot kg^{-1} \cdot min^{-1}$ in a sedentary population (Eston *et al.,* 2012). Encouragingly, the predictions from Study 2 (treadmill PRET, RPE 9–15) were similar in accuracy to those derived from studies using the 9-17 PRETs.

This novel application of RPE has advantages over other $\dot{V}O_2$max predictive methods that rely on heart rate as it is not susceptible to the errors associated with the prediction of maximal heart rate (Londeree & Moeschberger, 1984; Buckley *et al.,* 1998) and is not affected by medications (e.g. β-blockers) and environmental conditions (e.g. heat) (Kang *et al.,* 1998; Eston & Connolly, 1996). With this in mind, a suggestion consistently made has been that the PRET may be a useful tool in clinical populations in which heart rate responses to exercise are affected either by medications or clinical manifestations (e.g. atrial fibrillation). To-date, no study has explored this concept among unhealthy adults. Futhermore, the matter of $\dot{V}O_2$peak as the critierion, as opposed to $\dot{V}O_2$max, needs to be considered in clinical populations as many protocols are terminated based on

symptom-limited parameters rather than typical metabolic markers of maximal exertion. Therefore, the purpose of this study was to examine the efficacy of predicting $\dot{V}O_2$peak via continuous sub-maximal PRET protocol (with a limit of RPE 15) in heart failure patients where chronotropic incompetence is common and the use of beta-blockers widespread.

## 6.3 Method

### 6.3.1 Participants

Sixteen (14 male and two female) patients diagnosed with heart failure (age 70.4 ± 7.0 years, mass 84.2 ± 13.61 kg, stature 174 ± 8.4 cm) were recruited from a hospital Cardiology and Cardiac Rehabilitation Department with the aid of specialist cardiac nurses and the Consultant Cardiologist and Registrar hospital doctors. After receiving oral and written information on the study (Appendix 10), all volunteers gave their consent (Appendix 12) to participate and prior to each testing session completed a pre-test health check (resting ECG, echocardiogram, blood pressure and health status questionnaire – Appendix 6). All patients had an ejection fraction less than 40%, were classified as New York Heart Association (NYHA) II or III (Appendix 15) with respect to their heart failure and were prescribed cardio selective β-blockers (fourteen prescribed Bisoprolol and two Carvedilol). Full details of the inclusion and exclusion criteria for the study are tabled in Appendix 16. Ethical approval was granted by the NHS North West Research Ethics Committee (Appendix 5) and reported to the Research and Development office at the hospital.

### 6.3.2 Procedures

A repeated measures design was utilised in which patients attended the Cardiac Rehabilitation department at the hospital on three separate occasions (at 48-72 h intervals), once to perform a graded exercise test (GXT) to exhaustion ($\dot{V}O_2$peak) and two further times to perform a continuous, sub-maximal PRET. The PRETs were administered twice as previous studies have demonstrated that practice improves the accuracy and reliability of the $\dot{V}O_2$peak predictions obtained from them (Eston *et al.,* 2005; 2006; Faulkner *et al.*, 2007; also Studies 1-3 of this thesis). Moreover, they were performed after the GXT, which served the purpose of screening the patients for abnormal ECG changes during exercise or other complications. All exercise sessions were performed on the same electronically braked cycle ergometer (Lode Corival; Lode BV, Groningen, The Netherlands) at a cadence maintained between 50-80 revs·min$^{-1}$. This mode of exercise was selected as it allows exercising at very low workloads that can be finely controlled, and allows continuous undisturbed monitoring of heart rate, rhythm and blood pressure and is recommended in general for heart failure patients (Giannuzi *et al.,* 2001). All the data on the cycle's display (e.g. power output and heart rate) were obscured from patient view at all times to prevent any intensity-related feedback. Respiratory responses ($\dot{V}O_2$) and 12-lead ECG waves (Welch Allyn Inc. New York, USA) were measured continuously during each exercise session via an integrated cardiopulmonary breath-by-breath online gas analysis system (Medical Graphics Corporation, Breeze Suite, Minnesota, USA). Gas and volume calibrations were performed before each testing session in accordance with the manufacturer's

guidelines. Each participant was tested at a similar time of day on each occasion (within ± 2 h) to control for physiological variation caused by circadian rhythms (Reilly, 2007; Zwierska *et al.,* 2001; 2000). During all testing sessions a specialist cardiologist or registrar was present as a matter of safety. Participants were asked to refrain from vigorous exercise (48hrs), alcohol (48hrs), tobacco (3hrs) and caffeine (12hrs) before each testing session.

### 6.3.3 Graded exercise test (GXT)

The GXT ($\dot{V}O_2$peak) protocol required patients to perform a light (10 W) 5-minute warm-up, followed by an incremental continuous protocol starting at 10 W and increasing by 15 W every 3 minutes. During the last 15 seconds of each increment the patient was requested to provide his/her RPE via the 6-20 scale (Borg, 1998). When an RPE of 15 was indicated, the resistance was increased by 10 W and exercise continued until volitional exhaustion or if abnormal ECG changes were present. The attainment of $\dot{V}O_2$peak was evaluated upon patients reaching a state of volitional exhaustion (following some verbal encouragement) and being unable to maintain the pedal cadence (50-80 revs·min$^{-1}$), as suggested by Poole *et al*. (2008).

### 6.3.4 Sub-maximal perceptually regulated exercise test (PRET)

Prior to performing each PRET, patients were presented with a large cardboard format of the 6-20 RPE scale (Borg, 1998) and read out a set of instructions (see Study 1) specific to *regulating* exercise intensity with the scale.

Thereafter, and following a five-minute warm-up at 10 W and a five-minute rest, the patients were asked to regulate their intensity to match four RPE levels (9 – very light, 11 – light, 13 – somewhat hard, and 15 – hard (heavy)) presented in that order during a continuous protocol. The PRET commenced with no resistance on the cycle and a request to reach the required cadence (50–80 revs·min$^{-1}$) before instructing the investigator to adjust the intensity on the control panel to match the initial effort rating (RPE 9). The patients were given up to two minutes to adjust the exercise intensity (unbeknown to the patients this was in 5 W increments or decrements) to their satisfaction, then they cycled at that intensity for two minutes. One minute into the self-regulated bout a further opportunity to adjust the intensity was offered. At the end of the first bout, the next target RPE was requested (RPE 11) and the adjustment procedure was repeated. This continued for the third (RPE 13) and fourth (RPE 15) bouts, following which a five-minute cool-down at 10 W was completed. The mean $\dot{V}O_2$ and HR during the final 30 s of each RPE level were subsequently calculated.

### 6.3.5 Data analysis

Descriptive statistics (mean ± SD) and a two factor fully repeated measures ANOVA was calculated following confirmation of normal distributions (via the Shapiro-Wilk statistic) for the $\dot{V}O_2$ values across each exercise trial at each RPE level. In the manner of previous research in this area (Eston *et al.,* 2005; 2006; 2008; Faulkner *et al.*, 2007; also Studies 1-3) linear regression analyses ($\dot{V}O_2$ = a + b x RPE) were performed on individual $\dot{V}O_2$ data of each PRET to predict the

GXT-determined $\dot{V}O_2$peak at the theoretical RPE 20 end-point. Additional calculations were performed up to a ceiling of RPE 19 (Faulkner *et al.,* 2007) and for a truncated RPE range of 9-13. Separate paired *t*-tests were utilised for each predictive model to compare trial means to actual $\dot{V}O_2$peak scores. The absolute agreement between the GXT $\dot{V}O_2$peak values and those predicted from the PRETs was calculated with the 95% limits of agreement (LoA) technique, on the basis that the errors (differences) were found to be normally distributed and homoscedastic (Bland & Altman, 1986). The LoA (bias ± 1.96 x $SD_{diff}$) technique was also used to assess the reproducibility of the $\dot{V}O_2$max predictions across the two PRET trials, with the addition of the typical error ($SD_{diff}$ /√2; Hopkins, 2000) technique and the intraclass correlation coefficient (ICC), calculated via a two-way mixed effects model for absolute agreement. All data analyses were conducted using SPSS for Windows (version 18.0) and alpha was set at the 0.05 level.

## 6.4 Results

Whilst there were no adverse effects throughout the GXT and PRET trials, two patients who completed the GXT and the first PRET withdrew from the study due to health problems (unrelated to this study), leaving a sample size of 14. In addition, three patients in the first PRET trial did not complete the RPE 15 bout as they could not sustain the required intensity and soon fatigued (with $\dot{V}O_2$ levels approaching maximum). For two of these patients this was repeated in the second PRET. Similarly, one patient did not complete the RPE 13 bout in trial 1, although they did in trial 2. Accordingly, 11 patients completed all RPE levels (9–15) for both

trials, 13 patients completed RPE levels 9–13 in trial 1 and 14 completed both trials at these levels.

The individual correlations between RPE and $\dot{V}O_2$ values in both trials exceeded $r = 0.94$, except for one (0.76) in trial 1, and as a sample, increases in RPE level were accompanied by significant increases in mean $\dot{V}O_2$ ($F = 51.51$, df = 1.2, $p < 0.0005$; Table 6.1), HR ($F = 22.54$, df = 1.4, $p < 0.0005$; Table 6.2) and power output ($F = 82.71$, df = 1.1, $p < 0.0005$; Table 6.3).

**Table 6.1** Mean (± SD) oxygen uptake values ($ml \cdot kg^{-1} \cdot min^{-1}$) across two PRET trials ($n$ = 14 unless otherwise stated).

| **RPE level** | **Trial 1** | | **Trial 2** | |
|---|---|---|---|---|
| | **$\dot{V}O_2$** | **% $\dot{V}O_2$peak** | **$\dot{V}O_2$** | **% $\dot{V}O_2$peak** |
| **9** | 7.0 ± 1.2 | 46.9 ± 17.4 | 6.4 ± 1.0 | 42.0 ± 13.9 |
| **11** | 8.6 ± 1.5[a] | 56.3 ± 17.7 | 8.2 ± 1.4[b] | 52.5 ± 14.6 |
| **13** | 10.8 ± 2.4[c] | 65.8 ± 13.3 | 10.2 ± 2.4[a] | 64.1 ± 13.0 |
| **15** | 13.0 ± 3.1 | 75.3 ± 9.9 | 13.1 ± 3.2 | 75.4 ± 8.9 |
| **Criterion $VO_2$peak** | 16.5 ± 4.9 | | | |
| **Prediction Model** | **$RPE^{19}$** | **$RPE^{20}$** | **$RPE^{19}$** | **$RPE^{20}$** |
| **RPE 9 – 15** | 17.1 ± 5.0 | 18.2 ± 5.5[c] | 17.4 ± 5.1[b] | 18.5 ± 5.5 |
| **RPE 9 – 13**[b] | 16.3 ± 5.1[a] | 17.5 ± 6.0 | 15.9 ± 5.2 | 17.6 ± 5.9 |

[a] $n$ = 13; [b] $n$ = 14; [c] $n$ = 11

Neither the effect of trial on $\dot{V}O_2$ (F = 0.18, df = 1.0, *p* = 0.68), HR (F = 0.71, df = 1.0, *p* = 0.42) or power output (F = 0.006, df = 1.0, *p* = 0.94) was significant, nor was the trial x RPE level interaction (F = 0.88, df = 3.0, *p* = 0.46; F = 0.46, df = 1.4, *p* = 0.58 and F = 0.15, df = 3.0, *p* = 0.93), reflecting consistency in the intensity of the PRETs. The mean $\dot{V}O_2$peak predicted for each PRET was not significantly different (*p* > .05) to that obtained from the GXT (16.5 ± 4.9 $ml \cdot kg^{-1} \cdot min^{-1}$), and interestingly, the PRET predictions were most accurate in trial 2 for the RPE range of 9-15 and trial 1 for the 9-13 range, which is borne out by the lower LoA values (Table 6.4 & Figure 6.1).

**Table 6.2** Mean (± SD) heart rate ($beats \cdot min^{-1}$) across two PRET trials.

| RPE level | Trial 1 | Trial 2 |
|---|---|---|
| **9** | 83 ± 11.6 | 86 ± 17.3 |
| **11** | 94 ± 20.8 | 96 ± 25.1 |
| **13** | 105 ± 26.6 | 101 ± 24.0 |
| **15** | 109 ± 19.6 | 110 ± 21.9 |

**Table 6.3** Mean (± SD) power output (Watts) across two PRET trials.

| RPE level | Trial 1 | Trial 2 |
|---|---|---|
| **9** | 19 ± 9.4 | 18 ± 8.2 |
| **11** | 33 ± 12.0 | 33 ± 13.1 |
| **13** | 54 ± 19.8 | 53 ± 21.6 |
| **15** | 71 ± 27.7 | 75 ± 27.2 |

The reproducibility of the $\dot{V}O_2$peak predictions (Table 6.5) was optimal for the extrapolation to RPE 19 for both RPE models (9-15 and 9-13), as reflected by all three reliability statistics.

**Table 6.4** Bias ± 95% Limits of agreement (expressed as $ml \cdot kg^{-1} \cdot min^{-1}$) between PRET predicted and actual $\dot{V}O_2$peak values.

| Prediction model | Trial 1 | Trial 2 |
|---|---|---|
| | **(*n* = 11)** | **(*n* = 11)** |
| RPE 9 – 15 $RPE^{19}$ | -0.6 ± 4.2 | -0.2 ± 3.4 |
| RPE 9 – 15 $RPE^{20}$ | -0.5 ± 4.6 | -0.9 ± 3.9 |
| | **(*n* = 13)** | **(*n* = 14)** |
| RPE 9 - 13 $RPE^{19}$ | -0.6 ± 5.3 | -0.6 ± 5.5 |
| RPE 9 - 13 $RPE^{20}$ | 0.3 ± 5.7 | 0.3 ± 5.9 |

$RPE^{19}$ extrapolated to RPE 19
$RPE^{20}$ extrapolated to RPE 20

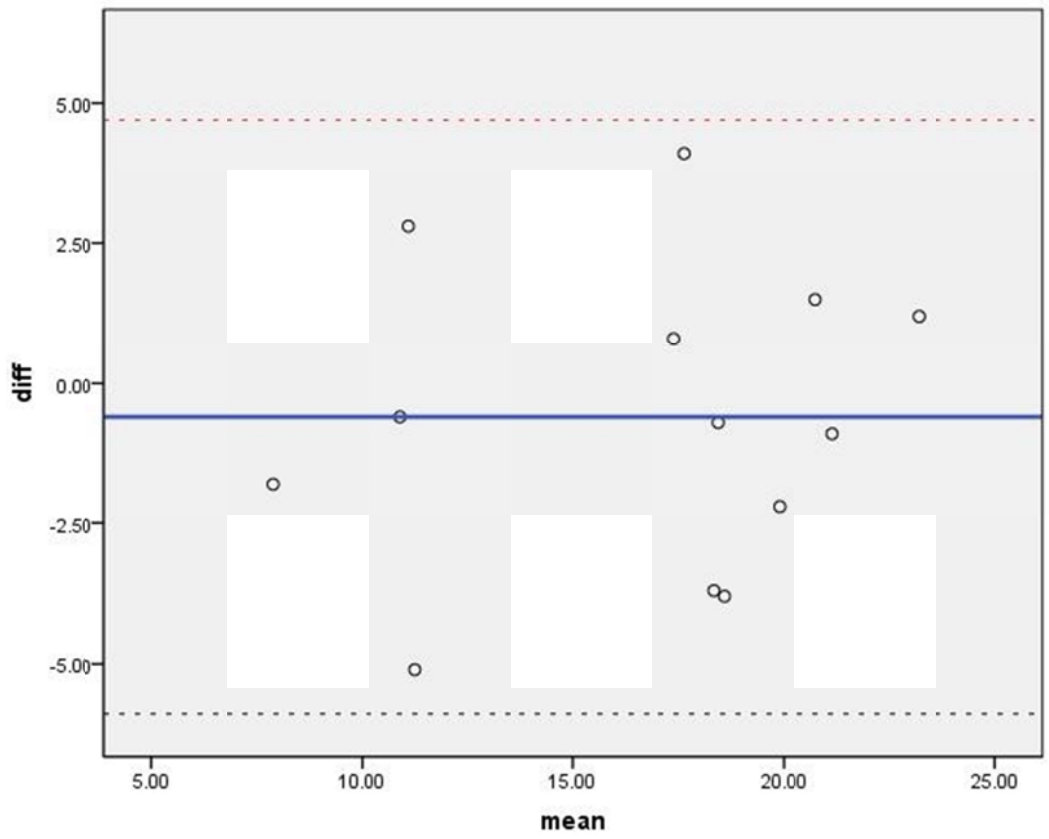


**Figure 6.1** Bland-Altman plot demonstrating the optimal LoAs for RPE 9 – 13 trial 1

**Table 6.5** Reliability of $\dot{V}O_2$peak predictions across repeated trials.

| Prediction model | ICC | 95% LoA[1] | Typical error[1] |
|---|---|---|---|
| RPE 9 – 15 RPE[19] (*n*=11) | 0.92 | -0.3 ± 4.4 | ± 1.57 |
| RPE 9 – 15 RPE[20] (*n*=11) | 0.92 | -0.4 ± 4.7 | ± 1.71 |
| RPE 9 - 13 RPE[19] (*n*=13) | 0.82 | 0.4 ± 6.5 | ± 2.35 |
| RPE 9 - 13 RPE[20] (*n*=13) | 0.83 | 0.3 ± 7.0 | ± 2.54 |

RPE[19] extrapolated to RPE 19
RPE[20] extrapolated to RPE 20
[1]$ml \cdot kg^{-1} \cdot min^{-1}$

## 6.5 Discussion

In this first application of a PRET among heart failure patients, the estimates of $\dot{V}O_2$peak generated can be interpreted very favourably with respect to previous research in this field, which, at best has yielded agreement of 0.2 ± 4.9 ml·kg$^{-1}$·min$^{-1}$ (Eston *et al.,* 2005). Moreover, the current study used a shorter protocol (up to an intensity of RPE 15, instead of 17) than previously. However, it is acknowledged that given the low actual mean $\dot{V}O_2$peak observed in this population (16.5 ± 4.9 ml·kg$^{-1}$·min$^{-1}$), the degree of agreement, expressed relative to this reflects differences between actual and predicted $\dot{V}O_2$peak of up to ± 20%. This statistic is more in keeping with previous studies among healthy participants (that included RPE 17) which reported prediction agreement in the region of 10–23% during cycle ergometry (Eston *et al.,* 2005; 2006; 2007; Faulkner *et al.,* 2007; also Study 1).

Notwithstanding the above, a principal observation in this study was that the upper level of the PRET (RPE 15) utilised was not suitable for all heart failure patients, three of whom were unable to complete this stage in both trials. Specifically, having regulated the exercise intensity to RPE 15 within one minute, it was evident they had selected a work rate that was approaching their GXT-determined maximum which required the investigator to intervene by stopping the trial. Six participants actually admitted (after the end of the protocol) that they found their effort during the RPE 15 bout drifted upwards rather quickly. This is perhaps due to their absolute narrow $\dot{V}O_2$ reserve (< 4 METS) where at this intensity (> 75% $\dot{V}O_2$peak) normal steady state $\dot{V}O_2$ kinetics was not possible. This appears to

agree with previous reports on the early onset of the anaerobic threshold in heart failure (Sullivan & Hawthrone, 1995). Notably, all six were categorised as NYHA III patients (moderate level of heart failure – indicated by a marked limitation of physical activity), whereas none of the NYHA II patients (mild level of heart failure – indicated by slight limitation of physical activity) encountered such a drift upwards in perceived exertion. Given that patients were exercising at 65–85% $\dot{V}O_2$peak (with eight patients exceeding 80% in both trials) at RPE 15, and exceeded the recommended intensity guidelines (30-70% $\dot{V}O_2$peak) for heart failure patients (Piepoli *et al.,* 2011), this intensity appears to be undesirable. Indeed, it might be that the protocol is just too long for some patients (13:06 ± 2:20 min and 12:55 ± 1:40 min in trials one and two, respectively), who typically have a severely impaired exercise tolerance (approximately 3 METS or less), as was likely the case for the three whom were unable to complete the RPE 15 level. Therefore, data analysis was centred on the more appropriate RPE 9-13 range. With these issues in mind, future studies should consider employing either a discontinuous PRET protocol (Eston *et al.,* 2007; also Study 1) that provides rest periods and an interval-type approach, which is recommended for heart failure patients (Coats *et al.,* 1992; Meyer, 2001), or alternatively, a lower intensity PRET with a ceiling of RPE 13 and duration of three minutes or less. Only one patient (classified as NYHA III) in trial 1 did not complete an intensity of RPE 13, whereas in trial 2 everyone successfully completed this stage, demonstrating the ability of the heart failure patients to adapt to the task of regulating exercise intensity via RPE.

The relative intensity at RPE 13 was between 52-77 % $\dot{V}O_2$peak (Table 6.1), a level more in keeping with the recommended intensity guidelines. Moreover, the optimal prediction of $\dot{V}O_2$peak from the RPE 9-13 model was -0.6 ± 5.3 $ml \cdot kg^{-1} \cdot min^{-1}$ (produced in trial 1, up to RPE 19), a worse case error relative to maximal values of 32%, which, albeit greater than for the current 9-15 model, is favourable compared to previous research among healthy participants (33%, Study 2 of this thesis); 53%, Eston *et al.,* 2012). That the best predictions were produced by extrapolating $\dot{V}O_2$ responses to RPE 19, and not 20, is intriguing, and indeed similar to the findings of Faulkner *et al.* (2007) from their study of active participants, and most recently Eston *et al.* (2012) in their healthy but sedentary participants during treadmill exercise. A possible explanation for this is that many studies have recognised that at maximum exertion an RPE of 20 is infrequently reported (Eston *et al.,* 2008; Faulkner *et al.*, 2007; St Clair Gibson *et al.,* 1999), a phenomenon that was also observed in Study 2 of this thesis where 100% of participants had a terminal RPE of 19. This observation was consistent among participants in both NYHA categories (II and III) for whom the predictions up to RPE 19 from the 9-13 model were optimal (and similar in magnitude) in trial 2. It is also interesting to note there was little difference in the predictions from the 9-13 model for trials 1 and 2 (Table 6.4), regardless of the model end-point. Contrary to this, all previous PRET research has shown improvements in $\dot{V}O_2$peak (or $\dot{V}O_2$max) prediction accuracy across repeated trials (Eston *et al.,* 2005; 2007; Faulkner *et al.,* 2007; Al-Rahmneh *et al.,* 2010; also Studies 1-3 of this thesis), although the key point is that one patient could not complete an RPE level of 13

during trial 1 due to overestimating the exercise intensity (although this was rectified during trial 2). This served to reinforce the importance of habituating participants to the task of regulating their own intensity and also the need to monitor them until they become competent in this task. It would have been interesting to know whether a further trial would have improved patients' regulation and improve the accuracy of the predictions, as previous studies have observed (Eston *et al.,* 2007; Faulkner *et al.,* 2007; Studies 1 and 2 of this thesis).

At peak work rate, no plateau in $\dot{V}O_2$ was observed in any of the patients during the GXT. Four patients were symptom-limited, where two reported breathing problems, one leg pain and one presenting with a ventricular ectopy. Surprisingly, for three of these patients their predictions of $\dot{V}O_2$peak were within 10% of measured values (1.8 $ml \cdot kg^{-1} \cdot min^{-1}$). In the fourth patient who presented with breathing difficulties his predicted $\dot{V}O_2$peak showed much less agreement with a difference of 30% (5.1 $ml \cdot kg^{-1} \cdot min^{-1}$) compared to actual. It is quite possible that their maximum perceived exertion may be adjusted to take into account their symptom-limited maximum (i.e. a patient's true maximum may be 25 $ml \cdot kg^{-1} \cdot min^{-1}$ but their symptom limited maximum may be 20 $ml \cdot kg^{-1} \cdot min^{-1}$, and his/her maximum RPE could be adjusted to this lower value), but further research is needed to confirm this. None of these patients exhibited any problems during regulation between RPE levels 9–13.

If absolute accuracy of the $\dot{V}O_2$peak is necessary then using a PRET protocol may be unsuitable, but previous research in healthy participants has shown the PRET to be as good, if not better, than heart rate predictive methods (Faulkner *et al.,* 2007). Indeed, such methods would not have been useful in this population as four had atrial fibrillation and one was fitted with a pacemaker, making any prediction based on heart rate highly questionable.

The test re-test bias ± limits of agreement for the 9–13 model were 0.4 ± 6.5 $ml \cdot kg^{-1} \cdot min^{-1}$ and for 9–15 -0.3 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$ between the two trials, which are similar to previous investigations that have included an intensity of RPE 17 and three trials (see Study 1), and also with those using a truncated RPE range of 9-15 (Faulkner *et al.*, 2007, -0.6 ± 12.0 $ml \cdot kg^{-1} min^{-1}$; Eston *et al.*, 2007, 1.3 ± 9.7 $ml \cdot kg^{-1} \cdot min^{-1}$). Furthermore, if the typical error is used, the interpretation of the current study's findings is even better (± 2.4 $ml \cdot kg^{-1} min^{-1}$), although this only considers about two thirds of the participants and not the 95% described by the LoA procedure. Depending on which measure is used, a 14-38% change in $\dot{V}O_2$peak could be detected, whereas typical improvements in $\dot{V}O_2$peak for heart failure patients following a period of exercise training are 23-25% (Sullivan, Higginbottom & Cobb, 1989; Braith, Welsch, Feigenbaum, Kluess & Pepine, 1999). Such figures question whether the PRET protocol would be suitable as an indicator of improvement in $\dot{V}O_2$peak following rehabilitation, and further research is required to refine the protocol, instructions and determine how many practice sessions are required to make the protocol more sensitive.

The challenge for researchers and practitioners who wish to use PRETs among cardiac populations is compounded by the presumed inability of 5-10% of participants to understand and utilise the Borg RPE scale in the desired way (Borg, 1998, p. 15), as alluded to earlier in this thesis (Studies 1-3). During this study, the investigator had to provide instructions additional to the PRET-specific set (designed for the first study of this thesis) to three of the patients (of mixed NYHA classification) in trial 1, and two of the same patients in trial 2. The participants required more simplistic examples of what the exercise should feel like; one particular patient commented regarding RPE 13 that perhaps it should be described as, "it should feel like cycling up a gentle hill". Seven other patients requested that the instructions were read through twice and reiterated during the trial, indicating difficulties understanding the scale. It is clear that these patients would have benefitted from three or more trials, as noted in Studies 1–3 and related previous research (Eston *et al.*, 2012). If these two patients' data are removed, the prediction from RPE levels 9-13 with extrapolation to RPE 19 would be within 4.1 $ml \cdot kg^{-1} \cdot min^{-1}$ in trial 1 for the rest of the sample.

In conclusion, the regulation of exercise intensity within an incremental and continuous PRET which includes an upper limit of RPE 15 seemed too strenuous among heart failure patients, and therefore inappropriate. Instead, this patient group should not regulate exercise intensity above a RPE of 13, especially if classified as NYHA III. On a positive note, the current data suggest that the employment of the cycle PRET with a ceiling intensity of RPE 13 would be both safe and yield predictions of $\dot{V}O_2$peak that are as accurate and reliable as those

reported for healthy participants. Such predictions are worthwhile for exercise prescription but questionable for assessing improvements during rehabilitation. Further investigations are required in this patient population with respect to assessing the efficacy of a discontinuous cycle PRET (with a ceiling intensity of RPE 13), the effects of providing practice trials on the prediction of $\dot{V}O_2$peak, and whether the PRET offers acceptable predictions in other modes of exercise and populations with abnormal heart rhythm (e.g. atrial fibrillation etc.).

# Chapter 7

# General Conclusions

## 7.1 Main Findings

The main findings from the four studies reported within this thesis have demonstrated that healthy participants and a clinical population of heart failure patients can not only regulate their exercise intensity utilising Borg's 6–20 RPE scale, but can do so in a manner that allows their corresponding $\dot{V}O_2$ data to be exploited to provide generally acceptable and repeatable estimates of their maximal (or peak) oxygen uptakes. Moreover, this programme of research has addressed three areas that have been innovative and have significantly enhanced the limited research in this field, providing the first investigations into: a) the utility of a reduced intensity PRET (ceiling intensity of RPE 15); b) whether the PRET is appropriate for use during treadmill exercise, and, c) its appropriateness in a clinical population of β-blocked heart failure patients.

## 7.2 The prediction of $\dot{V}O_2$max from perceptually-regulated exercise of a reduced intensity

Although Study 1 utilised a protocol similar to that in the original studies of Eston and co-workers (with an RPE range of 9–17) to predict $\dot{V}O_2$max, it did incorporate several methodological improvements. The first related to the provision of original (production-mode) instructions for use with the PRET protocol, the second concerned placing the maximal GXT after the PRET trials (to enhance the external validity of the PRET by not providing a prior exercise anchoring session), and thirdly, the randomising of the RPE levels to test the integrity of the procedure. As a consequence, these changes appeared to improve the accuracy of the

protocol, as the agreement between predicted and measured values was better than in three of the previous investigations (Eston *et al*., 2006; Faulkner *et al*., 2007; Eston *et al*., 2008).

Informed by the refinements and outcomes of Study 1, advances in the area were made in Studies 2, 3, and 4. The most significant finding was that a protocol incorporating an intensity of RPE 17 (in excess of 80% $\dot{V}O_2$max or $\dot{V}O_2$peak) would not be suitable for sedentary and clinical populations. It was deemed inappropriate to use the data from truncated RPE ranges (e.g. 9–15 or 9–13), ignoring RPE 17, to predict $\dot{V}O_2$max as participants may have adopted some sort of pacing strategy throughout, being cognisant they had to work at an intensity equivalent to 'very hard' (RPE 17). Therefore for the first time, subsequent studies (3 and 4) employed a PRET with a ceiling intensity of RPE 15, a level more in keeping with general fitness prescription, the termination point in a variety of sub-maximal tests and a level that lowers the health risk associated with strenuous exercise.

Study 3 yielded optimal estimates of $\dot{V}O_2$max that were slightly less accurate than the earlier investigations of Eston *et al*. (2005), Eston *et al*. (2006) and Faulkner *et al*. (2007) that had utilised a protocol involving RPE 17, although similar to those of Eston *et al*. (2007). It seems likely that the inclusion of RPE 17 provides strong perceptual feedback to the exerciser, which impacts upon the nature of the physiological response and the subsequent predictions of maximal values. However, it is noteworthy that unlike the aforementioned studies, Study 3

used a discontinuous, randomised PRET; arguably, continuous, incremental protocols may be easier for participants to regulate their exercise intensity as successive levels require an upward adjustment only (and no recollection of what had come before). Notwithstanding this, the reliability of the 9-15 protocol was as good, if not better, than the previous investigations (Eston *et al*., 2007; Faulkner *et al*., 2007), potentially making it sensitive enough to be used to detect changes following a period of exercise training (in healthy populations).

Studies 2 and 4 similarly adopted a PRET with a ceiling intensity of RPE 15, although for the first time during treadmill exercise (Study 2) and on β-blocked heart failure patients during cycle ergometry (Study 4). Both investigations provided additional support for the utilisation of the PRET protocol that is discussed further in the following sections.

### 7.3 Utilisation of the PRET procedure during treadmill exercise

As all previous investigations had applied the PRET protocol during cycle ergometry only, and considering that walking is the principal mode of exercise for most people, it was logical to investigate the utility of a RPE 9-15 PRET during treadmill exercise. It was observed that the treadmill PRET provided estimates of $\dot{V}O_2$max that were in line with those from previous cycling-based studies that had used a ceiling intensity of RPE 17 (Eston *et al.,* 2005; 2006; Faulkner *et al.,* 2007), demonstrating the success of the shortened PRET in this mode of exercise. In addition, its reproducibility was analogous to that reported with a favourable

interpretation by Eston *et al.* (2007) and Faulkner *et al.* (2007) for their truncated 9–15 models during cycle ergometry. These were encouraging findings, which, interestingly, have been reinforced by a very recent treadmill-based study among active and sedentary participants (Eston *et al*., 2012).

### 7.4 Utilisation of the PRET procedure in clinical populations

With a growing body of evidence supporting the use of a PRET protocol in sedentary and active populations, a suggestion consistently made has been that it may be a useful tool in clinical populations, most notably in patients whose normal heart rate response to exercise is affected (for example, those with atrial fibrillation or on cardiac medications such as β-blockers). Therefore Study 4 addressed this fundamental point, exploring the predictive capabilities and appropriateness of the PRET (RPE 9– 15) on β-blocked heart failure patients classified as NYHA class II and III during cycle ergometry. A key observation during this study was that this patient group had severe difficulties regulating their exercise intensity at RPE 15. At this level, 73% of patients were working typically in excess of 80% $\dot{V}O_2$peak, with several drifting towards their GXT-determined maximum level, necessitating the premature cessation of the bout. Therefore, it is evident that exercise regulation at this intensity should not be advised for heart failure patients, particularly those classified as NYHA III. It was posited that this may have been due partly to the nature and/or length of the protocol (continuous lasting 2 minutes per RPE level plus 1–2 min adjustment time) being unsuitable. It has been suggested (Coats *et al.,* 1992; Meyer, 2001) that heart failure patients are more suited to interval-type

training with regular rest periods, employing a discontinuous PRET (as in Study 1) might have been more manageable. Owing to this limitation, the analysis was restricted to the data gathered from levels 9–13. On a positive note, it emerged that a PRET with a ceiling intensity of RPE 13 was safe and yielded predictions of $\dot{V}O_2$peak that were as accurate as those observed in previous investigations on healthy participants. Whether these predictions are sensitive enough for assessing improvement following a rehabilitation programme are questionable, but provide worthwhile data for exercise prescription purposes.

### 7.5 Applying the PRET in clinical and non-laboratory environments

The main arguments for the introduction of the PRET are: (i) its use in environments where the normal heart rate response is affected (e.g. cardiac medications or heat), (ii) it is sub-maximal and therefore suitable for sedentary or clinical populations, and (iii) as an alternative protocol when expensive gas analysis laboratory equipment is not available (e.g. hospital clinics or fitness centres). Investigations to-date have provided convincing evidence that the PRET is as good as if not better at predicting $\dot{V}O_2$max than protocols utilising heart rate (Eston *et al*., 2007) and also is suitable in sedentary (Eston *et al*., 2007; Faulkner *et al*., 2007) and clinical populations (Study 4). However, all of these investigations have measured $\dot{V}O_2$ via expensive gas analysis equipment at each RPE level to enable the extrapolation to $\dot{V}O_2$max (or $\dot{V}O_2$peak), equipment that would *not* be available in hospital clinics or fitness centres where this protocol might be used. A possible solution to this might be for the intensity of the cycle (W) or treadmill

(speed and gradient) exercise observed at each stage during a PRET to be converted to oxygen uptake values via the likes of the ACSM (2010) metabolic calculations [1.8 x (resistance (kg) x 6 (m) x pedal frequency (revs·min$^{-1}$) / body mass (kg)]. To explore the merit of this, the predictive accuracy of the PRET protocols using this technique for the data gathered in Studies 3 (healthy participants, cycle ergometer, RPE 9–15; Table 7.1) and 4 (heart failure patients, cycle RPE 9–13; Tables 7.2) has been calculated (see below).

**Table 7.1** The agreement (expressed as LoA ml·kg$^{-1}$·min$^{-1}$) between ACSM predicted and measured $\dot{V}O_2$max values (based on Study 3 PRET data).

| Prediction model | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| $RPE_{19}$ | -5.5 ± 21.2 | -5.61 ± 16.2* | -6.25 ± 17.1* |
| $RPE_{20}$ | -3.2 ± 22.4 | -3.4 ± 16.7 | -4.1 ± 17.6 |

* Significant difference at the 0.05 level

The use of the ACSM equations in Study 3 (Table 7.1) instead of measured $\dot{V}O_2$ values yielded a deterioration of the prediction accuracy of the PRET (-3.4 ± 16.7 for ACSM equations versus -4.5 ± 11.8 ml·kg$^{-1}$·min$^{-1}$ from measured $\dot{V}O_2$ values. Although the bias is slightly smaller (this would have no practical implication) the LoA for the ACSM equations were wider (worse) by 4.9 ml·kg$^{-1}$·min$^{-1}$ than those based on the measured $\dot{V}O_2$ values. Now whilst it is known that the ACSM metabolic equations contain an inherent degree of error (Lang, Latin,

Berg & Mellion, 1992) when assessed against measured $\dot{V}O_2$ values during cycle ergometry (approximately 2.4–3.7 ml·kg$^{-1}$·min$^{-1}$), on the face of it these figures are not encouraging. The ACSM-based prediction would, in the worst case scenario, reflect an error of 41% of the actual measured values which exceeds those reported in previous PRET-related studies. Notwithstanding this, the situation with regard to the heart failure patients' data of Study 4 is rather interesting.

In contrast to the calculations presented in Table 7.1 (above), substituting the measured $\dot{V}O_2$ for the ACSM calculated values had little effect on the LoA (optimal in trial 2 for the $RPE_{19}$ model across RPE levels 9–13; Table 7.2). The LoA are only slightly wider (worse) in the ACSM calculated (4.1 ± 5.9 ml·kg$^{-1}$·min$^{-1}$) PRET than when measured $\dot{V}O_2$ values were used (-0.6 ± 5.5 ml·kg$^{-1}$·min$^{-1}$), mainly on account of the bias widening by 3.5 ml·kg$^{-1}$·min$^{-1}$.

**Table 7.2** The agreement (expressed as LoA ml·kg$^{-1}$·min$^{-1}$) between ACSM predicted and measured $\dot{V}O_2$max values (based on Study 4 PRET data).

| **Prediction model** | **Trial 1** | **Trial 2** |
|---|---|---|
| $RPE_{19}$ | 3.2 ± 7.1 | 4.1 ± 5.9 |
| $RPE_{20}$ | 4.3 ± 7.4 | 5.2 ± 6.2 |

It is noticeable that the measured PRET $\dot{V}O_2$ prediction slightly under-estimated the actual $\dot{V}O_2$peak, whereas the ACSM calculations over-estimated it, possibly owing to patients not achieving a plateau in $\dot{V}O_2$ (being unable to) within each 2-minute RPE level of the PRET (especially at RPE 13), which is an assumption built into the ACSM calculations.

### 7.6 Directions for future research

Whilst this programme of research has added to a growing body of evidence supporting the suitability of a PRET for predicting $\dot{V}O_2$max (or $\dot{V}O_2$peak), it has raised a series of questions for future research. In particular, these include: (i) should $\dot{V}O_2$ data be extrapolated to RPE 19 or 20; (ii) can a PRET be used effectively in other modes of exercise; (iii) what is the optimum number of practice trials required; (iv) is a discontinuous or continuous protocol more appropriate; (v) can a PRET be usefully employed among other clinical populations? Also the sensitivity of the PRET needs to be investigated following an intervention so there is a real need for a randomised controlled trial ivolving the PRET.

There is no clear message as to whether the extrapolation to predict $\dot{V}O_2$max (or $\dot{V}O_2$peak) should be to RPE 19 (commonly reported maximum) or 20 (theoretical maximum). This line of enquiry emerged due to a number of studies highlighting that at volitional exhaustion RPE 20 was infrequently reported (Eston *et al*., 2008; Faulkner *et al*., 2007) and that participants typically reach their limit of fatigue at an RPE of 19 (in Study 2 100% of participants reported RPE 19 at

volitional exhaustion). Several studies have reported that the PRET typically under-predicts $\dot{V}O_2$max (Eston *et al*., 2006; Studies 1-3 of this thesis), therefore the extrapolation to RPE 20 (rather than RPE 19) seems to offer better agreement with criterion $\dot{V}O_2$max. As others have advocated extrapolation to RPE 19 (Faulkner *et al*., 2007; Eston *et al*., 2012; Study 4 of this thesis), further investigations are required to address these differences and determine the most appropriate prediction model, which could quite possibly be different depending on the mode of exercise or population being investigated. Indeed, the first studies into the efficacy of predicting $\dot{V}O_2$max via a PRET focused solely on cycle ergometry as this provides easy and fine control of exercise intensity and a relatively undisturbed monitoring of physiological responses. However, to-date, only two studies have utilised another mode of exercise (treadmill); Study 2 in this thesis and Eston *et al*. (2012). If the PRET protocol is to be used beyond the exercise physiology laboratory - in the community and among different/special populations – its application in a variety of exercise modes would be desirable, such as rowing, stepping and cross-trainer.

Allied to investigating the predictive validity of a PRET in different modes of exercise is the exploration of its reproducibility and the degree of familiarisation or practice required by exercisers in order to optimise its precision. Previous studies have shown an improvement in the reproducibility and accuracy over three repeated trials (Eston *et al*., 2006; 2007; Faulkner *et al*., 2007) and it would be interesting to know whether further trials would enhance exercise regulation, and

whether an optimum number of practice sessions exist. Moreover, the nature of the PRET protocol - whether discontinuous or continuous, incorporating incremental or randomised levels – needs to be investigated systematically to test the integrity of the PRET technique. As acknowledged in Study 4, the use of a discontinuous protocol (with rest periods) may be more appropriate for certain populations (such as cardiac patients, or possibly children), whereas a continuous incremental protocol might be best for others.

Since the first attempt to predict $\dot{V}O_2$max via a PRET (Eston *et al*., 2005) a pervasive rationale for its worthiness has been its potential use in situations where the normal heart rate response to exercise is affected, such as in clinical populations. Whilst Study 4 represents the first attempt to apply a PRET in such a population, and yielded some important findings (such as the inappropriateness level of RPE 15 and the corresponding need to implement a ceiling intensity of RPE 13), it was realised that other, more functionally capable clinical populations (for example, stable cardiac rehabilitation patients) are worthy of investigation, given the acknowledged significance of exercise in shaping their quality of life.

# Chapter 8

# References

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# Chapter 9:

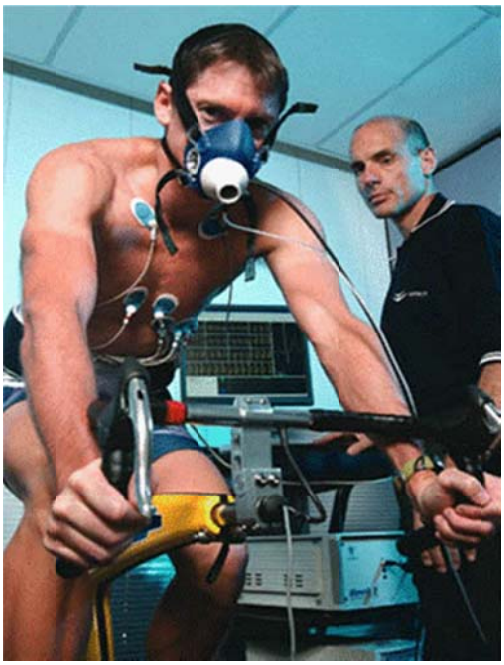
# Appendices

# Appendix 1

# Appendix 2

**Appendix 3**

# Volunteers Wanted!



Volunteers must be between the ages of 18 – 55 years, free from any medical illness that prevents you from performing moderate exercise.

***FREE*** fitness assessment for every volunteer recruited to the study.

If you are interested, please contact Mike Morris
Centre for Exercise and Nutrition Science (CENS).

Tel: 01244 513363

Mike Morris Tel: 01244 513363 | Mike Morris Tel: 01244 513363 | Mike Morris | Mike Morris Tel: 01244 513363 | MMike Morris Tel: 01244 513363

# Appendix 4

University of Chester

*Centre for Exercise and Nutrition Science*

*Reader and Research Co-ordinator*
***Dr Stephen Fallows***
*BSc, PhD*
Direct Line 01244 513407
Fax 01244 511310
s.fallows@chester.ac.uk

Mike Morris
Room CTW408
Centre for Exercise and Nutrition Science
University of Chester

22 November 2007

Dear Mike

**Study title:** **The prediction of $\dot{V}O_2max$ from perceptually regulated exercise**
**SREC reference:** **192/07/MM/CENS**
**Version number:** **1**

Thank you for sending the above-named application to the Faculty of Applied and Health Sciences' Research Ethics Committee for review.

The application has been considered on behalf of the Committee by Nick Clitherow as Lead Reviewer and reported to the Faculty Research Ethics Committee.

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form and supporting documentation.

The favourable opinion is given provided that you comply with the conditions set out in the attached document. You are advised to study the conditions carefully.

The final list of documents reviewed and approved by the Committee is as follows:

| Document | Version | Date |
|---|---|---|
| Application form | 1 | November 2007 |
| Participant information sheet | 1 | November 2007 |
| Participant consent form | 1 | November 2007 |
| Advertising poster | 1 | November 2007 |
| Pre-test questionnaire | 1 | November 2007 |
| Borg RPE instruction sheet | 1 | November 2007 |
| PGXT and GXT protocols and instructions | 1 | November 2007 |
| Data recording sheet | 1 | November 2007 |

# Appendix 5

NHS
National Research Ethics Service
North West 2 Research Ethics Committee – Liverpool Central
3rd Floor
Barlow House
4 Minshull Street
Manchester
M1 3DZ

Telephone: 0161 625 7818
Facsimile: 0161 237 9427

06 December 2010

University of Chester
Department of Clinical Sciences
Parkgate Road
Chester
CH1 4BJ

Dear

**Study Title:** **Predicting maximal oxygen uptake from a perceptually regulated exercise test (PRET) in cardiac rehabiliation patients.**
**REC reference number:** **10/H1005/79**

Thank you for your letter of 29 November 2010, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair.

**Confirmation of ethical opinion**

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

**Ethical review of research sites**

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

The Committee has not yet been notified of the outcome of any site-specific assessment (SSA) for the non-NHS research site(s) taking part in this study. The favourable opinion does not therefore apply to any non-NHS site at present. I will write to you again as soon as one Research Ethics Committee has notified the outcome of a SSA. In the meantime no study procedures should be initiated at non-NHS sites.

**Conditions of the favourable opinion**

The favourable opinion is subject to the following conditions being met prior to the start of the study.

This Research Ethics Committee is an advisory committee to the North West Strategic Health Authority
*The National Research Ethics Service (NRES) represents the NRES Directorate within the National Patient Safety Agency and Research Ethics Committees in England*

## Appendix 6

University of Chester

**Pre-test Questionnaire (Studies 1, 2, 3 & 4)**

Name:_____ Test date:_____

Address:_____

Contact number:_____ Date of birth:_____

In order to ensure that this study is as safe and accurate as possible, it is important that each potential participant is screened for any factors that may influence the study. Please circle your answer to the following questions:

1. Do you feel pain in the chest when you perform physical activity? YES/NO
2. In the past month, have you had chest pain when you were not performing physical activity? YES/NO
3. Do you lose your balance because of dizziness *or* do you ever lose consciousness? YES/NO
4. Do you have bone or joint problems (e.g. back, knee or hip) that could be made worse by a change in your physical activity? YES/NO
5. Is your doctor currently prescribing drugs for your blood pressure or heart condition? YES/NO
6. Have you injured your hip, knee or ankle joint in the last six months? YES/NO
7. Do you know of any other reason why you should not participate in physical activity? YES/NO

Thank you for taking your time to fill in this form.

University of Chester

Countess of Chester Hospital NHS
NHS Foundation Trust

# Study 4 – Patient History

Participant: _____

Patient ID: _____ Sex Male / Female

D.O.B: ___/____/____ Age_____

Ethnicity_____ Date of testing: ___/___/_____

Randomisation: _____ Session: Initial / Final

**Completed documents** (all must be ticked):

Consent ☐ Health Screen ☐ MLHFQ ☐

Checked patient against inclusion/exclusion criteria? YES / NO

**Pre-test measures:**

Height _____cm Weight: _____Kg

BMI: BP: _____/_____mmHg

**Medications and doses:**

**Heart Failure assessment:**

Echo ☐ BNP ☐ Ejection fraction: _____

HF aetiology: Ischaemic / Non Ischaemic

**Activity Level**

Sedentary / Moderate / Active

NYHA Class

Patient * I / II / III/ IV Investigator** I / II / III/ IV

*Please give the patient the NYHA classification sheet and ask them to choose what class they think they are in
**Please choose what class you think the patient is in based on your overall assessment. In addition to the information on the patient NYHA sheet we suggest:

Class 1: Can manage 2 flights of stairs or equivalent
Class 2: Can manage a flight of stairs or equivalent
Class 3: No symptoms at rest but has to stop after a few stairs
Class 4: Symptoms at rest (usually intermittent), activity very limited

## Appendix 7

University of Chester

### Participant Information Sheet (Study 1)

## The Prediction of Maximal Oxygen Uptake ($\dot{V}O_2$max) from Perceptually Regulated Exercise Tests.

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me if there is anything that is not clear or if you would like more information. Please take time to decide whether or not you wish to take part. Thank you for reading this.

**What is the purpose of this study?**

The purpose of this research is to evaluate a new method to predict a person's fitness level also known as their maximal oxygen uptake ($\dot{V}O_2$max). This new method will make it possible to estimate a person's fitness level without taking them to exhaustion and be based up them regulating the exercise intensity themselves. The study will take place over six months; however it will only involve you for ten to fifteen days, in which time you are required to attend five testing sessions.

**Why have I been chosen?**

The study aims to include a broad cross section of healthy individuals who are able and willing to perform a series of simple exercise tests. You are able to meet these criteria.

**Do I have to take part?**

It is up to you to decide whether or not to take part. If you decide to take part you will be given this participant information sheet to keep and be asked to sign a

consent form. If you decide to take part you are free to withdraw at any time, and a decision not to take part will not affect you in any way.

**What will happen to me if I take part?**

You will be required to attend five exercise testing sessions which will take place at the Human Performance Laboratory at the University of Chester, which will last approximately one hour each. There will be a break of two - three days between each testing session.

The first four sessions will involve you working to approximately 80% of your maximum on a cycle and in the final session working to exhaustion. In the first four sessions it is you that will regulate the intensity on the cycle using the rating of perceived exertion scale (a measurement of how hard it feels you are exercising). In all testing sessions the following measurements will be taken:

1. Oxygen consumption and carbon dioxide production (for which you will be required to wear a face mask).
2. Heart rate (for which you will be required to wear a belt around your chest).
3. Rating of perceived exertion (a measurement of how hard it feels while you are exercising).

Before each testing session your blood pressure will be measured and you will be required to complete two short questionnaires (there will be someone there to help you if you need it).

You will be required to abstain from the following prior to each testing session:

* Vigorous exercise 48hrs
* Alcohol 24hrs
* Tobacco 3hrs
* Caffeine 12hrs

**What are the possible disadvantages and risks of taking part?**

It is possible when undertaking the final two testing sessions, which will require you to exercise to exhaustion; you may experience a slight discomfort of panting, leg pain and/or fatigue. If this does occur, trained staff, who hold current first aid qualifications, will be on hand to assist you.

**What if something goes wrong?**

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Dr Kevin Lamb, Senior Lecturer, Department of Sport and Exercise Science, University of Chester, CH1 4BJ, 01244 513425

**Will my taking part in the study be kept confidential?**

All information which is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the study and his supervisor will have access to such information.

**What will happen to the results of the research study?**

The results will be written up in a report as part a PhD thesis and also possibly used for research publication. Individuals who participate will not be identified in any subsequent report or publication.

**Who may I contact for further information?**

If you would like more information about the research before you decide whether or not you would be willing to take part please contact:

Michael Morris
Centre for Exercise & Nutrition Science
University of Chester
Parkgate Road
Chester
CH1 4BJ
Tel: 01244 513363
e-mail: m.morris@chester.ac.uk

## Appendix 8

University of Chester

## Participant Information Sheet (Study 2)

## The Prediction of Maximal Oxygen Uptake ($\dot{V}O_2max$) from Perceptually-Regulated Exercise.

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me if there is anything that is not clear or if you would like more information. Please take time to decide whether or not you wish to take part. Thank you for reading this.

**What is the purpose of this study?**

The purpose of this research is to evaluate a new method to predict a person's fitness level also known as their maximal oxygen uptake ($\dot{V}O_2max$). This new method will make it possible to estimate a person's fitness level without taking them to exhaustion and be based up them regulating the exercise intensity themselves. The study will take place over six months; however it will only involve you for twelve to fifteen days, in which time you are required to attend four testing sessions.

**Why have I been chosen?**

The study aims to include a broad cross section of healthy individuals who are able and willing to perform a series of simple exercise tests. You are able to meet these criteria.

**Do I have to take part?**

It is up to you to decide whether or not to take part. If you decide to take part you will be given this participant information sheet to keep and be asked to sign a

consent form. If you decide to take part you are free to withdraw at any time, and a decision not to take part will not affect you in any way.

**What will happen to me if I take part?**

You will be required to attend four exercise testing sessions which will take place at the Human Performance Laboratory at the University of Chester, which will last approximately forty five minutes each. There will be a break of two - three days between each testing session.

The first three sessions will involve you working to approximately 70% of your maximum on a cycle and in the final session working to exhaustion. In the first three sessions it is you that will regulate the intensity on the cycle using the rating of perceived exertion scale (a measurement of how hard it feels you are exercising). In all testing sessions the following measurements will be taken:

1. Oxygen consumption and carbon dioxide production (for which you will be required to wear a face mask).
2. Heart rate (for which you will be required to wear a belt around your chest).
3. Rating of perceived exertion (a measurement of how hard it feels while you are exercising).

Before each testing session your blood pressure will be measured and you will be required to complete one short questionnaire (there will be someone there to help you if you need it).

You will be required to abstain from the following prior to each testing session:

* Vigorous exercise 48hrs
* Alcohol 24hrs
* Tobacco 3hrs
* Caffeine 12hrs

**What are the possible disadvantages and risks of taking part?**

It is possible when undertaking the final testing session, which will require you to exercise to exhaustion; you may experience a slight discomfort of panting, leg pain and/or fatigue. If this does occur, trained staff, who hold current first aid qualifications, will be on hand to assist you.

**What if something goes wrong?**

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor Sarah Andrew, Dean of Applied and Health Sciences, University of Chester, CH1 4BJ, 01244 513055

**Will my taking part in the study be kept confidential?**

All information which is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the study and his supervisor will have access to such information.

**What will happen to the results of the research study?**

The results will be written up in a report as part a PhD thesis and also possibly used for research publication. Individuals who participate will not be identified in any subsequent report or publication.

**Who may I contact for further information?**

If you would like more information about the research before you decide whether or not you would be willing to take part please contact:

Michael Morris
Centre for Exercise & Nutrition Science
University of Chester
Parkgate Road
Chester
CH1 4BJ Tel: 01244 513363 e-mail: m.morris@chester.ac.uk

University of Chester

## Appendix 9

### Participant Information Sheet (Study 3)

### The validity and reliability of predicting maximal oxygen uptake from a treadmill-based sub-maximal perceptually-regulated exercise test.

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me if there is anything that is not clear or if you would like more information. Please take time to decide whether or not you wish to take part. Thank you for reading this.

**What is the purpose of this study?**

The purpose of this research is to evaluate a new method to predict a person's fitness level also known as their maximal oxygen uptake ($\dot{V}O_2max$). This new method will make it possible to estimate a person's fitness level without taking them to exhaustion and be based up them regulating the exercise intensity themselves. The study will take place over six months; however it will only involve you for twelve to fifteen days, in which time you are required to attend four testing sessions.

**Why have I been chosen?**

You have been chosen due to you being the appropriate age, sex and being apparently healthy.

**Do I have to take part?**

It is up to you to decide whether or not to take part. If you decide to take part you will be given this participant information sheet to keep and be asked to sign a

consent form. If you decide to take part you are free to withdraw at any time, and a decision not to take part will not affect you in any way.

**What will happen to me if I take part?**

You will be required to attend four exercise testing sessions which will take place at the Physiology Research Laboratory at the University of Chester, which will last approximately one hour each. There will be a break of two - three days between each testing session. The first three sessions will involve you working to approximately 80% of your maximum on a treadmill and in the final session working to exhaustion. In the first three sessions it is you that will regulate the intensity on the treadmill using the rating of perceived exertion scale (a measurement of how hard it feels you are exercising). In all testing sessions the following measurements will be taken:

1. Oxygen consumption and carbon dioxide production (for which you will be required to wear a face mask).
2. Heart rate (for which you will be required to wear a belt around your chest).
3. Rating of perceived exertion (a measurement of how hard it feels while you are exercising).

Before each testing session your blood pressure will be measured and you will be required to complete one short questionnaire (there will be someone there to help you if you need it).

You will be required to abstain from the following prior to each testing session:

* Vigorous exercise 48hrs
* Tobacco 3hrs
* Alcohol 24hrs
* Caffeine 12hrs

**What are the possible disadvantages and risks of taking part?**

It is possible when undertaking the final testing session, which will require you to exercise to exhaustion; you may experience a slight discomfort of panting, leg pain

and/or fatigue. If this does occur, trained staff, who hold current first aid qualifications, will be on hand to assist you.

**What if something goes wrong?**

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor Sarah Andrew, Dean of Applied and Health Sciences, University of Chester, CH1 4BJ, 01244 513055

**Will my taking part in the study be kept confidential?**

All information which is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the study and his supervisor will have access to such information.

**What will happen to the results of the research study?**

The results will be written up in a report as part a PhD thesis and also possibly used for research publication. Individuals who participate will not be identified in any subsequent report or publication.

**Who may I contact for further information?**

If you would like more information about the research before you decide whether or not you would be willing to take part please contact:

Michael Morris
Centre for Exercise & Nutrition Science
University of Chester
Parkgate Road
Chester
CH1 4BJ Tel: 01244 513363 ; e-mail: m.morris@chester.ac.uk

University of Chester

**Appendix 10**

Countess of Chester Hospital NHS
NHS Foundation Trust

# Participant Information Sheet (Study 4)

**Title of Project:** A new method to predict aerobic capacity in cardiac patients.

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me if there is anything that is not clear or if you would like more information. Please take time to decide whether or not you wish to take part.

Thank you for reading this.

**What is the purpose of this study?**

The purpose of this research is to evaluate a new method to predict a person's fitness level also known as their maximal oxygen uptake ($\dot{V}O_2max$). This new method will make it possible to estimate a person's fitness level without taking them to exhaustion and be based up them regulating the exercise intensity themselves. The study will take place over four months; however it will only involve you for six to seven weeks, in which time you are required to attend three testing sessions at the Countess of Chester hospital.

**Why have I been invited?**

You have been chosen due to you being the appropriate age and taking beta-blocker medication.

**Do I have to take part?**

It is up to you to decide whether or not to take part. If you decide to take part you will be given this participant information sheet to keep and be asked to sign a consent form. If you decide to take part you are free to withdraw at any time, and a decision not to take part will not affect the research or your care in any way.

**What will happen to me if I take part?**

You will be required to attend three exercise testing sessions which will take place at the Countess of Chester hospital, which will last approximately one hour each. There will be a break of two days between the first two testing sessions. At this point you will be assigned to one of two groups, one group will wear a pedometer (this measures the amount of steps you take) and also complete an exercise diary. The other group will just carry on with their normal daily activities. You will then be asked to return to the Hospital following six weeks for a further test.

The first session will require you familiarise yourself with the equipment and exercise protocols and then work to your maximum on a cycle and the following session you will work at approximately 75% of your maximum. In the second session it is you that will regulate the intensity on the cycle using the rating of perceived exertion scale (a measurement of how hard it feels you are exercising). The third and final visit will be a repeat of the first test (maximal) that you undertook. In all testing sessions the following measurements will be taken:

1. Oxygen consumption and carbon dioxide production (for which you will be required to wear a face mask).
2. Heart rate (for which you will be required to wear stickers on your chest).
3. Rating of perceived exertion (a measurement of how hard it feels while you are exercising).

Before each testing session your blood pressure will be measured and you will be required to complete two short questionnaires (there will be someone there to help you if you need it).

At the first visit and final visit a 5ml blood sample (a teaspoonful) will be taken.

You will be required to abstain from the following prior to each testing session:

* Vigorous exercise 48hrs
* Alcohol 24hrs
* Tobacco 3hrs
* Caffeine 12hrs

Your GP will be notified of your involvement in the research via a letter.

**What are the possible disadvantages and risks of taking part?**

It is possible when undertaking the first and final testing sessions, which will require you to exercise to maximum; you may experience a slight discomfort of panting, leg pain, and/or fatigue. If this does occur, trained hospital staff, will be on hand to assist you.

**What are the possible benefits of taking part?**

You may receive health benefits from performing the several bouts of exercise during the exercise tests and/or your participation in the six weeks pedometer and diary group encouraged exercise. Also, you may learn to use independently the perception of effort rating scale to regulate your exercise at an appropriate health-promoting intensity.

**What if something goes wrong?**

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor Sarah Andrew, Dean of Faculty of Applied Sciences, University of Chester, CH1 4BJ, 01244 513055.

**Will my taking part in the study be kept confidential?**

All information which is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the study and the consultant cardiologist will have access to such information.

**What will happen to the results of the research study?**

The results will be written up in a report and also possibly used for research publication. Individuals who participate will not be identified in any subsequent report or publication.

**Who may I contact for further information?**

If you would like more information about the research before you decide whether or not you would be willing to take part please contact:

Michael Morris BSc, MSc, FHEA
Department of Clinical Sciences
University of Chester
Parkgate Road
Chester
CH1 4BJ
Tel: 07789642792
Email: m.morris@chester.ac.uk

University of Chester

## Appendix 11

**The Prediction of Maximal Oxygen Uptake ($\dot{V}O_2max$) from Perceptually-Regulated Exercise Tests**

**Consent Form**

I (print name) _____ consent to participating in this physiological assessment on the following terms.

1. I have read the participant information sheet (attached) and understand what I will be required to do. I am aware of the purpose of the tests, the potential benefits and the risks.
2. I understand that I will be undertaking physical exercise at or near the extent of my capacity and that there is possible risk in the physical exercise at that level, that is, episodes of transient light headedness, fainting, abnormal blood pressure, chest discomfort and nausea.
3. I understand that this may occur, though the staff in the laboratory will take proper care in the conduct of the assessment, and I will fully assume that risk.
4. I know that I am not obliged to complete the tests. I am free to stop the test at any point for any reason.
5. I understand that the information obtained from the test will be treated confidentially with my right to privacy assured. However, the information may be used for statistical or scientific reasons with privacy retained.
6. I hereby agree that I will present myself for testing in a suitable condition having abided by the requirements for diet and activity prescribed for me by the researcher.

Participant's signature:_____ Date:_____

Researcher's name:_____

Researcher's signature:_____ Date:_____

## Appendix 12

Centre Number:
Study Number:

# CONSENT FORM (Study 4)

**Title of Project:** A new method to predict aerobic capacity in cardiac patients.

**Name of Researcher:** Michael Morris
**Participant ID:**

Thank you for reading the information about our research project. If you would like to take part, please read and sign this form.

PLEASE INITIAL THE BOXES IF YOU AGREE WITH EACH STATEMENT:

| | | |
|---|---|---|
| 1. | I have read the information sheet version dated 23/02/2011 for the above study and have been given a copy to keep. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. | ☐ |
| 2. | I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected. | ☐ |
| 3. | I agree to give a sample of blood for research in this study. I understand how the sample will be collected, that giving a sample for this research is voluntary and that I am free to withdraw my approval for use of the sample at any time. | ☐ |
| 4. | I understand that my GP will be informed of my participation. | ☐ |
| 5. | I know how to contact the research team if I need to. | ☐ |
| 6. | I agree to participate in this study | ☐ |

| | | |
|---|---|---|
| _____ | _____ | _____ |
| Name of Patient | Date | Signature |
| _____ | _____ | _____ |
| Name of Person taking consent (if different from researcher) | Date | Signature |
| _____ | _____ | _____ |
| Researcher | Date | Signature |

1 for patient; 1 for researcher; 1 to be kept with hospital notes

# Appendix 13

| | |
|---|---|
| 6 | No exertion at all |
| 7 | Extremely light |
| 8 | |
| 9 | Very light |
| 10 | |
| 11 | Light |
| 12 | |
| 13 | Somewhat hard |
| 14 | |
| 15 | Hard (heavy) |
| 16 | |
| 17 | Very hard |
| 18 | |
| 19 | Extremely hard |
| 20 | Maximal exertion |

Borg, 1985

**Figure 1.** The Borg RPE scale (Borg, 1998).

### Instructions to participants:

While exercising we want you to rate your perception of exertion, i.e. how heavy and strenuous the exercise feels to you. The perception of exertion depends mainly on the strain and fatigue in your muscles and on your feeling of breathlessness or aches in the chest. Look at this rating scale; we want you to use this scale from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion".

9 corresponds to "very light" exercise. For a normal, healthy person it is like walking slowly at his or her own pace for some minutes.

13 on the scale is "somewhat hard" exercise, but it still feels OK to continue.

17 "very hard" is very strenuous. A healthy person can still go on, but he or she really has to push him or herself. It feels very heavy, and the person is very tired.

19 on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.

Try to appraise your feeling of exertion as honestly as possible, without thinking about what the actual physical load is. Don't underestimate it, but don't overestimate it either. It's your own feeling of effort and exertion that's important, not how it compares to other people's. What other people think is not important either. Look at the scale and expressions and give a number. Any questions?

University of Chester

**Appendix 14**

# $VO_2$max Data Record Sheet

Participant: _____ D.O.B: _____

Date: _____

Session: Signed consent form: YES/NO

Height (cm): Weight (Kg):

BMI: BP:

$VO_2$max protocol:

| Stage | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Watts | | | | | |
| HR | | | | | |
| $VO_2$ | | | | | |
| RPE | | | | | |

**Start:** **RPE:**

**$VO_2$:**

**Finish:** **HR:**

University of Chester

# PRET Data Record Sheet

Participant: _____ D.O.B: _____

Date: _____

Session: Signed consent form: YES/NO

Height (cm): Weight (Kg):

BMI: BP:

Order of RPE (9 – 17):

| | | | | | |
|---|---|---|---|---|---|
| RPE | | | | | |
| Start | | | | | |
| Finish | | | | | |
| Watts | | | | | |
| HR | | | | | |
| $VO_2$ | | | | | |

## Appendix 15



Name: _____

D.O.B._____

Participant ID:

# New York Heart Association Classification

The following classification system is used by doctors to quantify how badly affected patients are by their heart failure. Please read the descriptions below and tell us what class you feel you are in.

| Class | Patient Symptoms |
|---|---|
| Class I (Mild) | No limitation of physical activity. Ordinary physical activity does not cause undue fatigue, palpitation, or dyspnea (shortness of breath). |
| Class II (Mild) | Slight limitation of physical activity. Comfortable at rest, but ordinary physical activity results in fatigue, palpitation, or dyspnea. |
| Class III (Moderate) | Marked limitation of physical activity. Comfortable at rest, but less than ordinary activity causes fatigue, palpitation, or dyspnea. |
| Class IV (Severe) | Unable to carry out any physical activity without discomfort. Symptoms of cardiac insufficiency at rest. If any physical activity is undertaken, discomfort is increased. |

# Appendix 16

**Inclusion and exclusion criteria for Study 4 on heart failure patients**

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| ✓Age 18 years or older. | × Coronary artery disease with active angina evidenced by chest pain in the two weeks prior to enrolment |
| ✓Left ventricular ejection fraction < 40%. | × Inability to quantify left ventricular function due to poor echo images. |
| ✓New York Heart Association Symptom Class IV. | × Major co-morbidities that restrict them from using an exercise cycle e.g. neuromuscular/skeletal limitations. |
| ✓ Low risk of exercise induced complications (based on initial medically supervised exercise test, as adjudged by the Consultant Cardiologist). | × Uncontrolled hypertension (Systolic BP persistently >170mmHg Diastolic >100mmHg).<br>× Severe aortic stenosis, hypertrophic cardiomyopathy or other causes of left ventricular outflow tract obstruction. |
| ✓ Stable medical therapy (not expected to undergo major changes in medication during the duration of the study). | × Patients awaiting surgical or percutaneous revascularisation.<br>× Decompensated cardiac failure or acute systemic illness.<br>× Acute myocarditis or pericarditis. |
| | × Untreated, potentially life-threatening cardiac rhythm disturbance |

## Appendix 17

## A CD of SPSS data can be found on the inside of the back cover